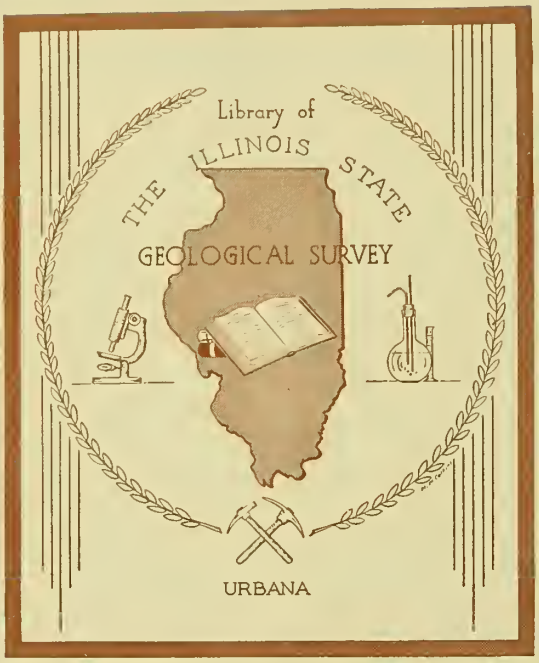

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DEPARTMENT OF REGISTRATION AND EDUCATION
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STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*

REPORT OF INVESTIGATIONS—NO. 34

CONTRIBUTIONS TO THE STUDY OF COAL

Banded Ingredients of No. 6 Coal and Their Heating Values as Related to Washability Characteristics

AND

Preliminary Report on Unit Coal-Specific Gravity Curves of Illinois Coals

BY

L. C. McCABE, D. R. MITCHELL, AND G. H. CADY

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BANDED INGREDIENTS OF NO. 6 COAL AND THEIR HEATING VALUES AS RELATED TO WASHABILITY CHARACTERISTICS

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BANDED INGREDIENTS OF NO. 6 COAL AND THEIR HEATING VALUES AS RELATED TO WASHABILITY CHARACTERISTICS

By L. C. McCabe,[1] D. R. Mitchell,[2] and G. H. Cady[3]

INTRODUCTION

Purpose of the Investigation

A comprehensive investigation of the nature of Illinois coal, anticipating the application of the knowledge obtained to the preparation and utilization of the coal, was initiated in 1931 as part of the program of mineral researeh by the State Geologieal Survey. The coal investigation was started with the systematic examination of column samples of Herrin (No. 6) coal in southwestern and southern Illinois. Such examinations by this and other laboratories have directed attention to the importance of reeognizing the fundamental differenees in the banded ingredients of bituminous coals such as are mined in Illinois.

The present bulletin describes an investigation of the redistribution of the banded ingredients in the fractions obtained by standard float-and-sink methods and the effect of such redistribution upon the ash content and heat value of the separated product. The results obtained suggest certain implications with respect to the combustion characteristics of the prepared coal. The investigation, as carried on, made possible the determination of (1) the usual float-and-sink data for the coals investigated, (2) the extent of the separation and/or concentration of the banded ingredients in the various fractions, and (3) the possible effect of the redistribution of the banded ingredients upon the ash content and heat value of the fractions.

Scope of the Investigation

The investigation employed samples of Herrin (No. 6) coal from 10 mines (Table 1 and Fig. 1) in southwestern and southern Illinois, the samples representing the general variations in the seam in the southern part of the State.

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[1] Assistant Geologist, Coal Division, Illinois State Geological Survey, Urbana.
[2] Assistant Professor, Mining and Metallurgical Engineering, University of Illinois, Urbana.
[3] Senior Geologist and Head of Coal Division, Illinois State Geological Survey, Urbana.

FIG. 1. Map of Illinois showing locations of the mines sampled.

TABLE 1.—*Location of mines by county*

Mine A	St. Clair	Mine F	Randolph
Mine B	St. Clair	Mine G	Perry
Mine C	St. Clair	Mine H	Franklin
Mine D	Montgomery	Mine I	Franklin
Mine E	Washington	Mine J	Williamson

The sampling, experimental tests and laboratory procedure were as follows:

(1) Initial channel and columnar sampling
(2) Standard float-and-sink separation
(3) Chemical analysis of fractions
(4) Megascopic and microscopic determination of the banded ingredients and mineral matter
(5) Compilation and interpretation of data

COMPARISON WITH PREVIOUS INVESTIGATIONS

Numerous float-and-sink tests have previously been made on Illinois coals;[4] the present tests supplement but do not duplicate earlier information. The cleaning possibilities of the coals studied in the present investigations are shown by the standard washability curves, but these data are supplemented by an additional series of curves, not accompanying previous reports, which indicate the effect of cleaning on heating values.

The determination of the distribution of heat values among the different fractions and the graphical delineation of the information are important additions to conventional float-and-sink data. The latter provide a control on the ash content of the product of a cleaning operation and the additional data make possible greater uniformity of quality.

The value of the calorific data would undoubtedly be greater if, as may eventually happen, an improvement in heat quality would insure a premium price on a coal, for in this case larger losses from cleaning could be endured. But even under present conditions where the producer is primarily interested in selling a certain quantity of coal and the consumer in buying a certain quantity of heat, it may be of sales advantage to be able to produce a coal of higher calorific value if only a slight tonnage loss is sustained thereby.

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[4] Coal washing in Illinois: Univ. of Illinois Eng. Exp. Sta. Bull. 69, 1913.
Dry preparation of bituminous coal at Illinois mines: Univ. of Illinois. Eng. Exp. Sta. Bull. 88, 1916.
Cleaning tests of central Illinois coals: U. S. Bureau of Mines, Tech. Paper 361, 1925.
Coal washing investigations, methods, and tests: U. S. Bureau of Mines Bull. 300, 1929.
Washability tests of Illinois coal: Univ. of Illinois Eng. Exp. Sta. Bull. 217, 1930.
The possible production of low ash and low sulfur coal in Illinois: Univ. of Illinois Eng. Exp. Sta. Bull. 258, 1933.

Thus it is possible to reduce the ash of one of these coals from 14.28 per cent to 8 per cent by cleaning at a point which will give 91 per cent tonnage recovery. At the same time 98.5 per cent of the B.t.u. would

FIG. 2. Cutting a column of No. 6 coal. The face sample was composed of cuttings from the channel to the right of the column.

be recovered and the B.t.u. value of the clean coal would be 12,485 as compared with 11,615 for the uncleaned coal. The consumer would not only buy less ash and sulfur but would receive 7.5 per cent more heat

than is present in an equal tonnage of untreated coal. It is quite reasonable to believe, furthermore, that coal at, let us say, 12,600 B.t.u., might sell at a premium above the price received for coal of less heat value. In such a case it would be important for the producer to know the loss that would be entailed in increasing the heat value of his coal to the higher specification.

An additional distinctive feature of this investigation, with respect to Illinois coals at least, is the determination of the extent of separation and concentration of the banded ingredients (vitrain, clarain and fusain) effected by the float-and-sink process. To accomplish this, samples of each fraction were studied as they came from the separating liquid, using an ore-dressing microscope.

In the course of a parallel investigation, the proportions of ingredients in the column samples of these coals had been carefully determined. With this information at hand a rough check on the values obtained in the study of the float-and-sink fractions was possible.

Acknowledgments

The greater part of the experimental data were gathered by the senior author as a graduate student in the Mining Engineering Laboratory of the University of Illinois. The associate authors were active in directing the work and in preparing the report. The release of the laboratory data for publication by the Dean of the College of Engineering and the Head of the Department of Mining and Metallurgical Engineering is gratefully acknowledged.

The writers take pleasure likewise in acknowledging the cooperation of the management of the mines where samples were collected and of Dr. O. W. Rees, Analytical Division of the State Geological Survey, and his assistants for chemical analyses.

PROCEDURE

Channel Sampling

A face sample from each mine provided the material for the tests. This consisted of the coal cut down along one channel adjacent to a column sample (Fig. 2) and supplied 10 to 15 pounds of coal for each foot of the seam. An effort was made to duplicate as nearly as possible the tipple feed involved in the cleaning process. In nine of the ten mines therefore, no impurities were excluded from the face samples because in these mines cutting machines are operated in the bottom of the coal and the entire fall of coal is loaded, the larger sizes being hand picked at the tipple. In the mine in Washington County the character-

istic clay "blue band", normally 1½ to 3 inches thick, thickens to 8 inches. Cutting machines are operated in this band, removing the greater part of it, and any clay left adhering to the coal is removed during loading. The "blue band" was therefore excluded from the sample taken in this mine.

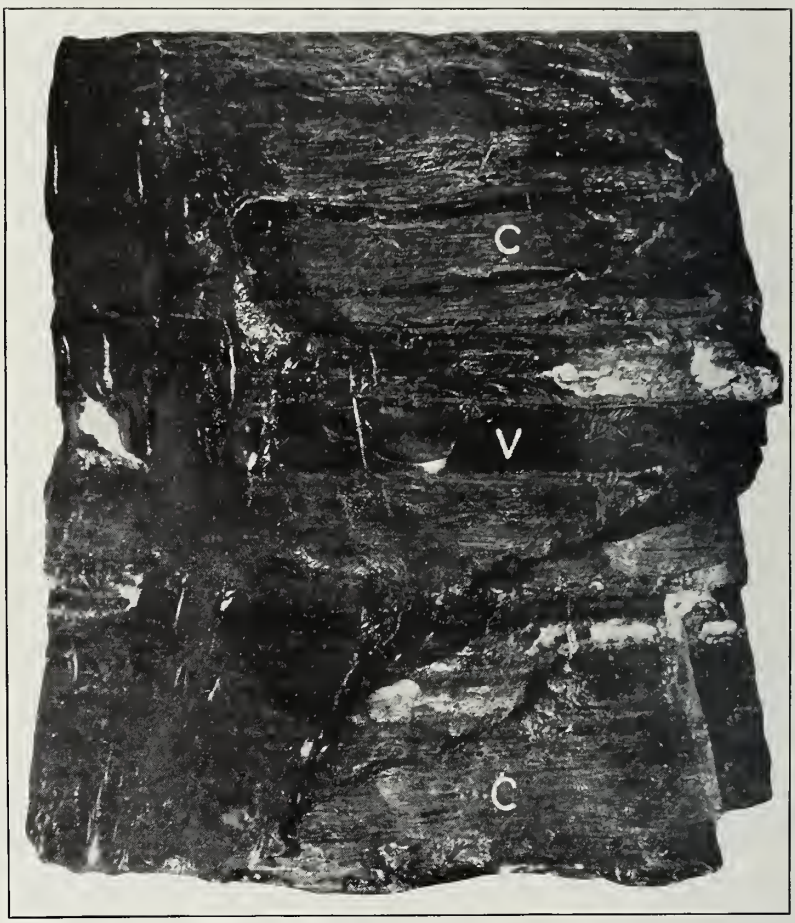


FIG. 3. A typical block of No. 6 coal, natural size, showing two varietes of banded ingredients, vitrain (V) and clarain (C).

LABORATORY PREPARATION OF CHANNEL SAMPLE

Each sample when cut down was sealed in a large can in the mine and transported to the laboratory where it was pulverized to minus ¼ inch. From this a sample of about 2 pounds was then cut out with a

riffle and a sample varying from 6 to 10 pounds was taken for the float-and-sink procedure as described by Callen and Mitchell.[5]

The material passing a 48-mesh Tyler standard screen was excluded from the head sample used in the washability tests as this fine material remains in suspension for some time and contaminates the solutions used in the specific gravity separations. The material remaining on the 48-mesh screen was air-dried for 24 hours before the float-and-sink tests were made.

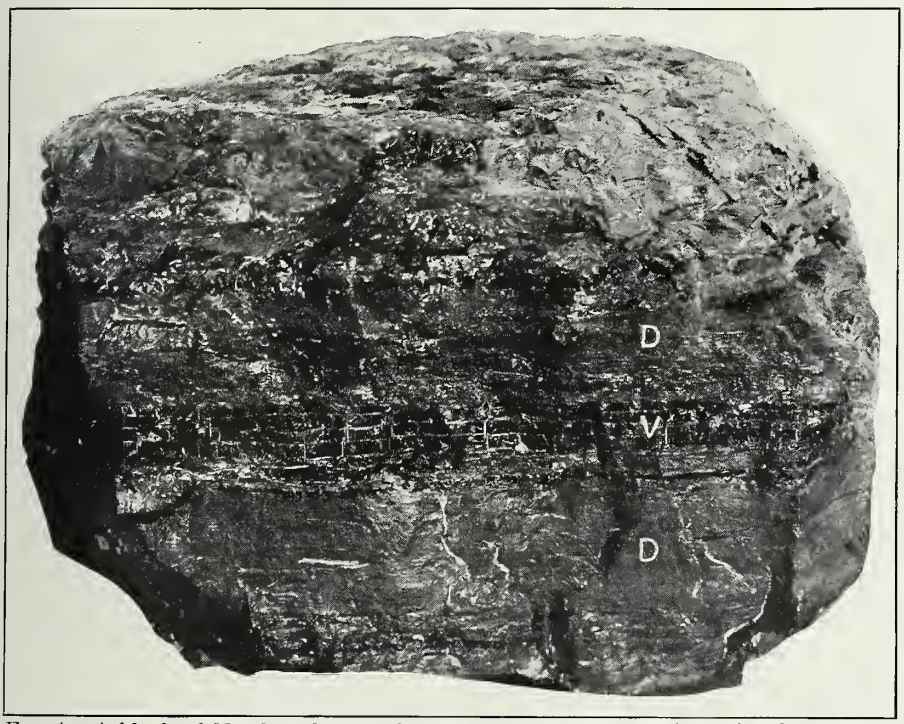


FIG. 4. A block of No. 6 coal, three-fourths natural size, showing a band of vitrain (V) between two wider bands of splint coal (durain, D).

Mixtures of benzene and carbon tetrachloride were used in preparing the series of liquids with specific gravities of 1.30 to 1.50 and mixtures of carbon tetrachloride and bromoform were used in preparing the heavier end of the series up to 2.0 specific gravity. Separations were made on the ten samples at the following specific gravities: 1.30, 1.35, 1.40, 1.50, 1.70, and 2.0. After gravity separation the fractions were dried in the air before an electric fan for a period of 24 to 48 hours.

[5] Callen, Alfred C., and Mitchell, David R., Washability tests of Illinois coals: Univ. of Illinois Eng. Exp. Station Bull. 217, p. 32, 1930.

A 10- to 20-gram sample was riffled from each fraction for microscopic study. The remainder of the fraction was used in chemical analysis.

Moisture, ash, and total sulfur determinations were made on each fraction. B.t.u. determinations, which are seldom included in float-and-sink work, were made on all fractions except the 2.0 specific gravity float and the 2.0 specific gravity sink. The latter determinations furnished the data for the construction of the B.t.u. curves.

PHYSICAL CHARACTER OF THE BANDED INGREDIENTS

Megascopic Character and Distribution of the Banded Ingredients

These coals are of the normal banded bituminous type. In the terminology of Stopes[6] the brilliant jet-black coal is vitrain, the glossy finely laminated coal is clarain, the dull laminated grayish coal, commonly known as splint, is durain. Fusain is the mineral charcoal (Figs. 3, 4, and 5).

Table 2.—*Percentages of banded ingredients*

Mine	County	Banded coal ingredients				Banded impurities		
		Vitrain	Clarain	Durain	Fusain	Pyrite	Bone	Clay
A	St. Clair.....	13.16	76.51	.....	3.38	5.12	.....	1.83
B	St. Clair.....	7.83	83.09	.....	2.62	4.76	.....	1.70
C	St. Clair.....	9.95	77.58	.....	7.43	1.82	1.33	1.89
D	Montgomery...	19.5	62.1	14.9	.8	1.5	.....	1.2
E	Washington....	13.40	68.70	15.0	2.9	.....	.....	(*a*)
F	Randolph.....	14.76	75.88	.....	4.77	.....	.....	4.59
G	Perry.....	19.00	69.90	.....	4.50	.....	2.6	4.00
H	Franklin.....	18.81	77.68	.....	1.50	.42	.61	.98
I	Franklin.....	22.70	72.40	.....	2.3	.10	1.60	.9
J	Williamson....	20.1	76.55	.....	1.35	.....	2.0	.....

(*a*) Eight-inch clay band removed in mining.

The values obtained in the measurements of the banded ingredients made on polished surfaces of the columnar sections of the seam (Table 2) are, as previously stated, an indication of the proportion in which the ingredients should occur in the channel sample used in the float-and-sink tests.

[6] Stopes, Marie C., "The Studies on the Composition of Coal," The four visible ingredients in banded bituminous coal: Proc. Roy. Soc., London, Vol. 90B, p. 470, 1919.

Clarain and vitrain are essentially complementary in occurrence, clarain comprising the greater part of the coal. The clarain average for the mines studied was 74.03 per cent, the values ranging from 62.1 to 83.0 per cent of the seam. A coal with a high percentage of clarain is

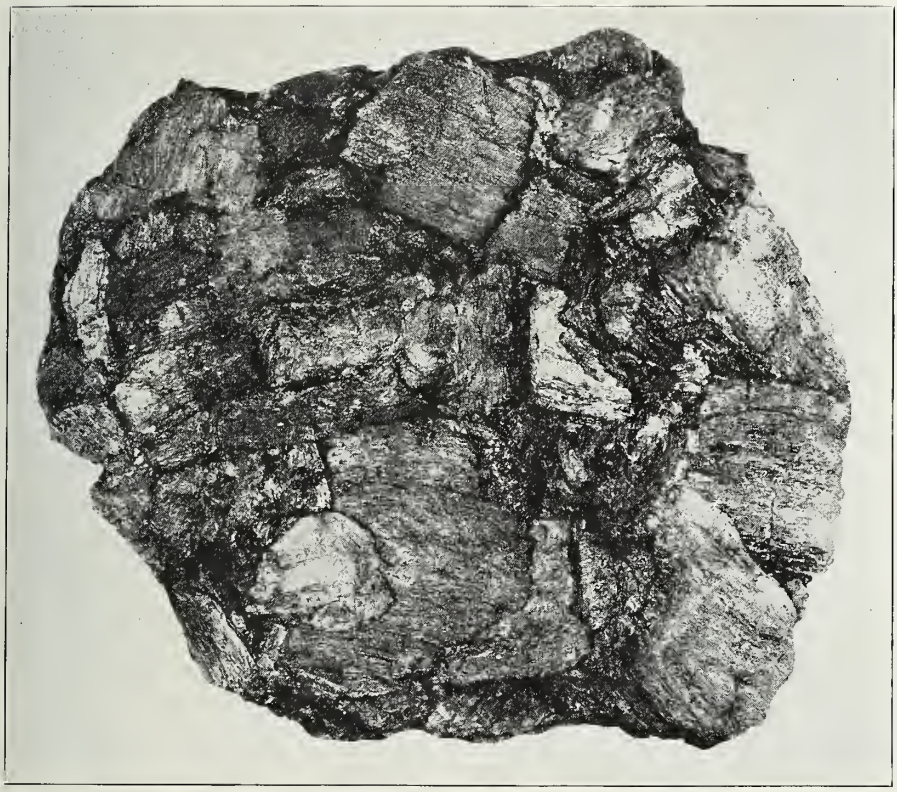


FIG. 5. Block of coal composed partly of mineralized fusain.

usually relatively low in its content of vitrain, and, conversely, much vitrain indicates less clarain. The vitrain content of the coal from Montgomery, Perry, Franklin, and Williamson counties is relatively high. Mine J, in Franklin County, showed a maximum for the group of 22.7 per cent vitrain, mine B, in St. Clair County, a minimum of 7.8 per cent.

Durain is an uncommon ingredient in Illinois coals, although locally bands 2 inches thick have been observed. In mine D in Montgomery County and in mine E in Washington County durain comprises 14.9 and 15.0 per cent of the seam respectively.

The quantity of fusain in the coals studied varies from a maximum of 7.4 per cent in St. Clair County (Mine C) to a minimum of 1.3 per cent in Williamson County (Mine J) the average being 3.0 per cent. But the amount of fusain does not indicate its importance in the preparation and utilization of the coal. Fusain is porous and friable, readily breaking away from the coal. It is the chief source of the dust in coals; therefore, any problem of dedusting is concerned principally with its removal. Mineral matter in the form of calcite, pyrite, and kaolinite is often associated with fusain because of its porosity.

Turning to the channel samples we find that the effect of float-and-sink procedure is to bring about a selective concentration of vitrain and clarain and of the mineral matter in different fractions, the fusain being largely removed in the dust.

TABLE 3.—*Specific gravity distribution of banded ingredients in sample from Mine J*

(Per cent by volume)

Specific gravity	Vitrain	Clarain	Fusain	Mineral matter
1.30 float	10.7	4.3	trace	.0
1.35 float	6.1	20.1	trace	.0
1.40 float	2.2	34.3	trace	.0
1.50 float	.8	12.2	.1	.2
1.70 float	.3	2.1	.1	.3
2.00 float	.2	1.0	.1	1.5
2.00 sink	.2	.9	.1	2.2
Total	20.5	74.9	.4	4.2

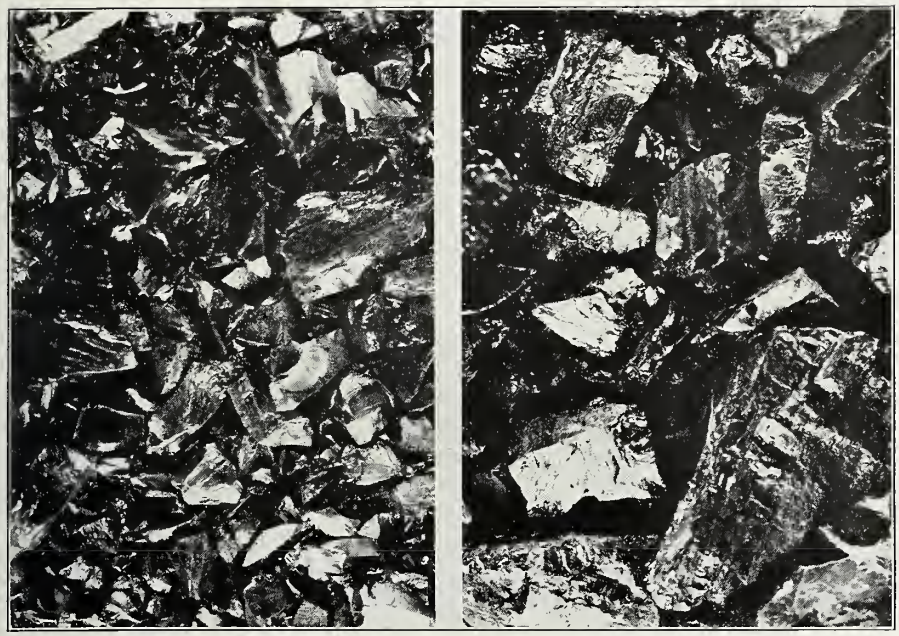
The ingredients in the gravity fractions from mine J in Williamson County as determined by microscopic identification of fragments, were so distributed that the 1.3 specific gravity fraction contained 52.2 per

EXPLANATION OF FIG. 6A

FIG. 6A. Fragments of coal of low specific gravity and low ash and sulfur content, separated by float-and-sink methods. (× 3)

a. Vitrain, coal floating in a liquid of 1.30 specific gravity. Note the comparatively small size of particles in this fraction.

b, *c*, *d*. Fractions composed predominantly of large angular pieces of clarain.



a. sp. gr. 1.30 float *b.* sp. gr. 1.35 float

c. sp. gr. 1.40 float *d.* sp. gr. 1.50 float

FIG. 6A. (Explanation on p. 16.)

cent of the total vitrain in the sample, 71.3 per cent of the fraction being vitrain. The fractions 1.35 to 1.70 inclusive contained 91.7 per cent of the clarain.

Fusain, as stated, was largely removed in the minus 48 mesh "dust" and was not carried through the float-and-sink process. However, occasional needlelike strands of the unmineralized or "soft" variety of fusain are present in the fractions of 1.30, 1.35, and 1.40 specific gravity. The "hard" variety of fusain, which commonly occurs as bundles of mineralized strands, is more noticeable in the fractions heavier than 1.40 specific gravity.

The mineral matter is concentrated in the three heaviest fractions (1.70 float, 2.0 float, and 2.0 sink).

The distribution of the banded ingredients in the various fractions of coal from Mine J is shown in the accompanying illustrations (Figs. 6A and B). The vitreous, brilliant, homogeneous appearance, and conchoidal fracture of the vitrain in the 1.30 specific gravity fraction (Fig. 6A-a) is in distinct contrast with the angular, more earthy, dull appearance of the high-ash coal in the 1.70 and 2.0 specific gravity fractions (Fig. 6B-e, f, g). The 2.0 specific gravity sink fraction is largely calcite or kaolinite plates, pyrite, clay, or shale. The bright, angular, laminated coal of the 1.35, 1.40 and 1.50 specific gravity fractions (Fig. 6A-b, c, d) consists largely of clarain.

Microscopic Nature of Fractions in Thin and Polished Sections

Microscopic verification of megascopic determinations, using thin sections and polished surfaces of individual fragments, readily demonstrated that the rougher identification was sufficiently accurate for all practical purposes. The illustrations (Fig. 7A thin sections, and 7B, C, D, polished fragments) indicate the microscopic appearance of the general type of material found in the different fractions but they do not begin to embrace the range of specific variation.

Vitrain such as composes a large part of the 1.30 fractions is readily identified megascopically (Fig. 6A-a). Frequently when observed in thin section it is highly resinous (Fig. 7A-a) or may display

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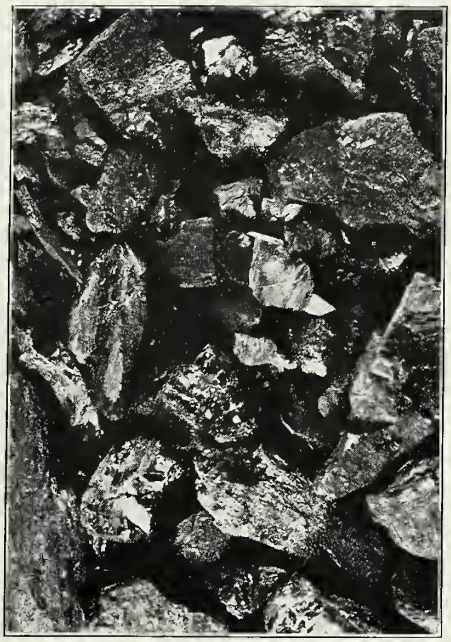
EXPLANATION OF FIG. 6B

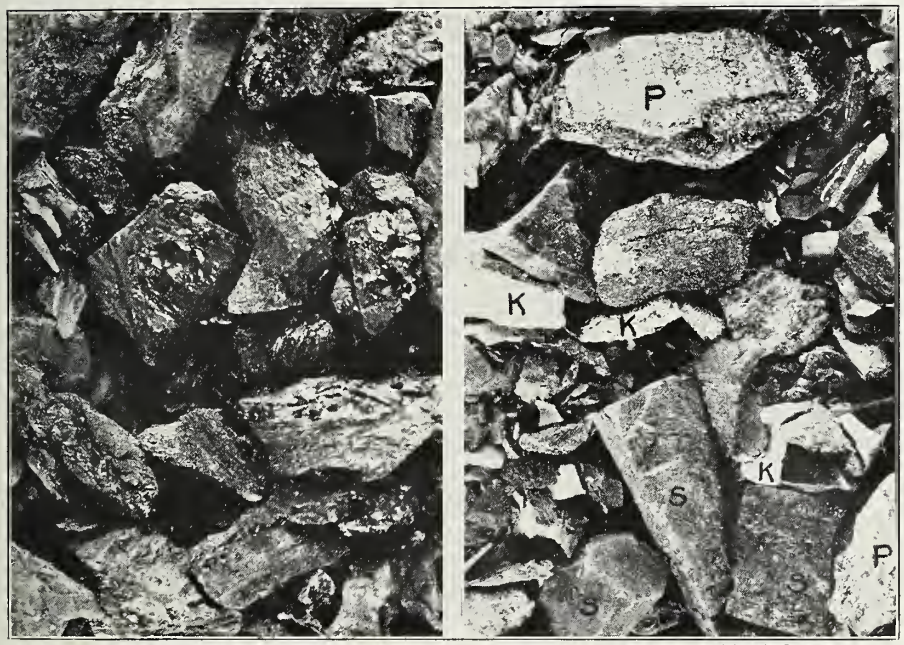
Fig. 6B. Mineral matter concentrated in fractions of high specific gravity. (× 3)

e, f. Mineral matter in these fractions occurs finely disseminated through the coal or as fine plates.

g. Fraction consists largely of calcite or kaolinite plates (K), pyrite (P), "slate" or shale (S).



e. sp. gr. 1.70 float



f. sp. gr. 2.00 float *g*. sp. gr. 2.00 sink

FIG. 6B. (Explanation on p. 18.)

cellular plant structure (Fig. 7A-b). These illustrations are representative of the microscopic appearance of the vitrain bands, which are known to have had their origin in the wood or bark of plants.

The coal found in fractions of 1.35, 1.40, and 1.50 specific gravity consists largely of clarain, which even megascopically lacks homogeneity. The photographs (Figs. 7A, c, d) illustrate this lack of homogeneity, but by no means indicate its extent. Typical low-ash clarain (Fig. 7A-c), cut approximately across the bedding, contains a predominance of fine laminae of micro-vitrain, representing shreds of woody material. Deposited among the accumulation are the spores and pollen of the flora—these appear as white, lenticular bodies in the figure. Along with the vegetable debris is a slight amount of ash-forming material. The black areas and strips in the illustration are either pyrite or fusain, both of which are opaque in thin section.

EXPLANATION OF FIG. 7A

FIG. 7A. Thin-sections from float-and-sink fractions shown in figure 6A.

a Vitrain showing elliptical shaped resin bodies containing numerous vacuoles. In thin section this coal in translucent; the groundmass is usually orange-red in transmitted light and the resin bodies appear wine-red.

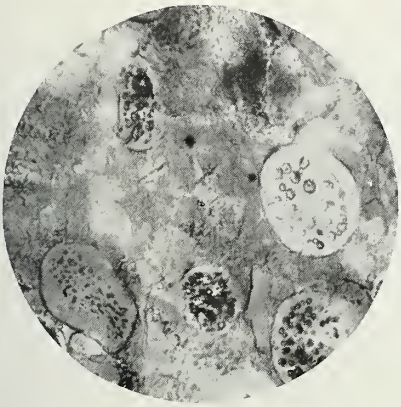
b Vitrain showing well developed cellular plant structure. Such structure is not uncommon in vitrain but is usually less conspicuous, as in upper and lower portion of figure. The cell bodies are filled with material of unknown character and origin. That part of the vitrain composed of closely compacted cell wall material is orange-red in transmitted light and the material filling the cells is light yellow.

c Typical translucent clarain (attritus), cut across the bedding, consisting of thin laminae of microvitrain and small lenticular white pollen or spore bodies. The micro-vitrain has an orange-red color in transmitted light and the spores are light yellow.

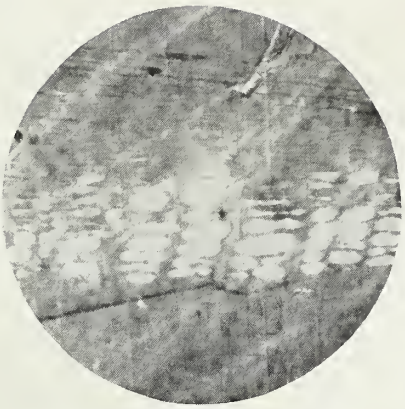
d Fusain in clarain (attritus) is frequent. The hazy white areas are open or mineral-filled cells in the fusain which is opaque and hence appears black. About a third of the material shown consists of clarain or translucent attritus. The section is cut approximately parallel to the bedding.

e Mineralized fusain, the mineral matter filling the cell cavities. Sections of fusain are only slightly translucent in thin sections and are frequently completely opaque or black.

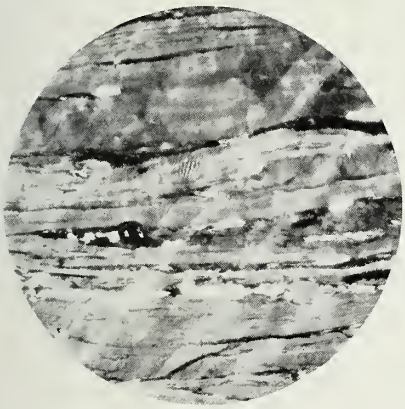
f. Translucent clarain (attritus) which contains considerable disseminated pyrite. The section is approximately parallel to the bedding.



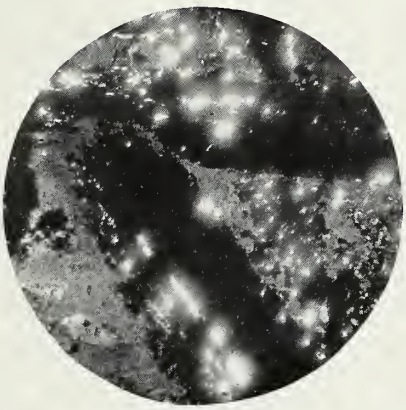
a. sp. gr. 1.30 float (× 100)



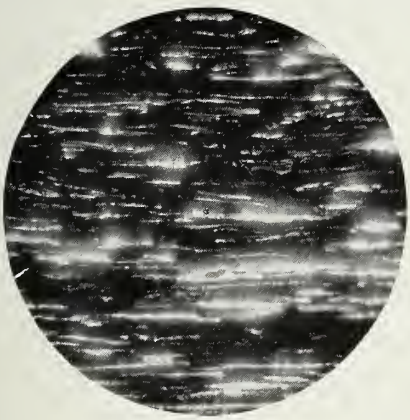
b. sp. gr. 1.30 float (× 100)



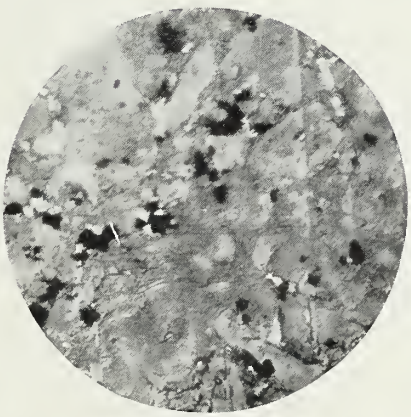
c. sp. gr. 1.35 float (× 50)



d. sp. gr. 1.40 float (× 50)



e. sp. gr. 1.50 float (× 25)



f. sp. gr. 1.50 float (× 50)

FIG. 7A. (Explanation on p. 20.)

g. sp. gr. 1.70 float (× 25)

h. sp. gr. 2.00 float (× 25)

FIG. 7B. Polished surfaces of fragments of coal and mineral matter from float-and-sink fractions of high specific gravity.
g Vitrain (V) embedded in a groundmass of "bone" coal (B).
h Bands of vitrain (V) separated by "bone" coal (B).

Fusain may occur as opaque masses embedded in the translucent clarain (Fig. 7A-d). A single fragment of fusain, when viewed at low magnification in the microscope (Fig. 7A-e), appears opaque except where the preparation has broken through mineral-filled cell cavities. It is through such cell openings that mineral-bearing solutions at some time found easy passage and place for deposition, resulting in coal fragments of high specific gravity and ash content. Clarain may contain pyrite in disseminated form (Fig. 7A-f) which in thin section appears as small black areas, thereby considerably increasing its specific gravity.

When much mineral matter is present in coal it is very apparent on polished surfaces whether the coal and the mineral matter are intimately mingled as in bone coal (Figs. 7B-g and 7C-i) or interlaminated (Fig. 7B-h) or whether the minerals occur in relatively pure masses of pyrite (Figs. 7C-j and 7D-k) or of kaolinite (Fig. 7D-l). Other occurrences than those pictured are common, but the illustrations serve to indicate the microscopic appearance and general type of material found in the fractions of high specific gravity.

ANALYSIS OF THE BANDED INGREDIENTS

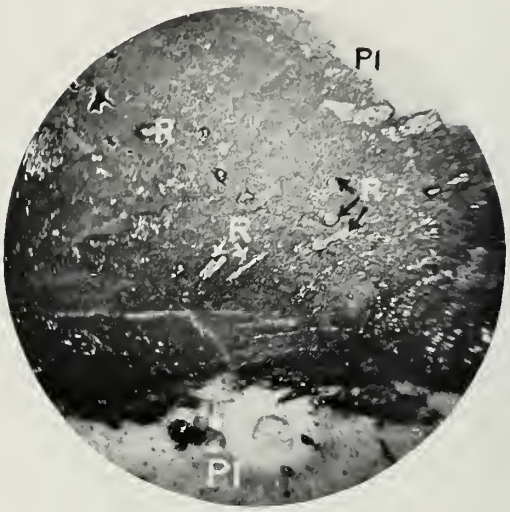
Sampling of Bands

The banded ingredients from three mines in coal No. 6, only one of which, however, is among the group included in the float-and-sink studies, have been analyzed in connection with this investigation. The ingredients were picked from the coal at the face, placed in cans, and sealed in the mine. The poor lighting usually made accurate selection of vitrain a slow process, so that to save time a small sample of carefully cleaned vitrain was powdered in a mortar, sealed in a small vial and inserted in the larger and less carefully cleaned sample. On reaching the laboratory the small sample was used for mine moisture determination and the larger sample was carefully hand cleaned for more complete analysis.

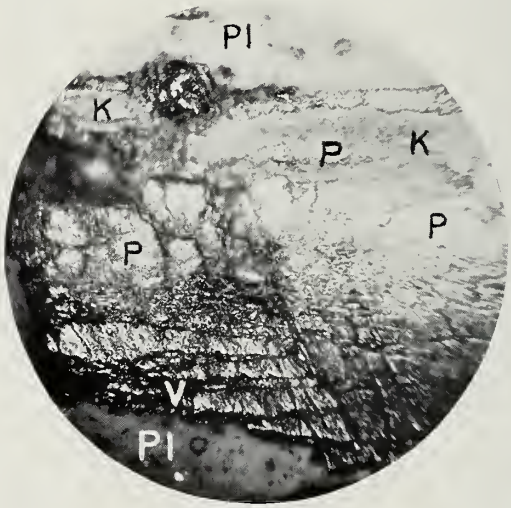
All material in the fusain sample not passing a 20-mesh Tyler standard screen was discarded. This eliminated pyrite nodules and the larger mineralized particles from the samples submitted for analysis.

With reasonable care in sampling to exclude vitrain bands and adhering fusain, clarain was easily collected in quantity because of its relative abundance.

Durain is of such small importance that no samples were collected for analysis.



i. sp. gr. 2.00 float (× 25)



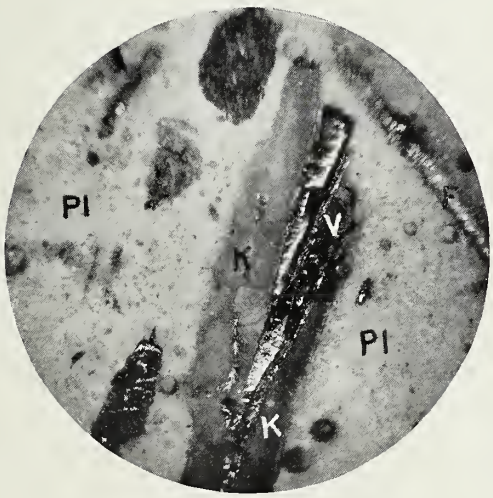
j. sp. gr. 2.00 sink (× 25)

FIG. 7C. Polished surfaces of fragments of coal and mineral matter from float-and-sink fractions of high specific gravity.

i Small resin bodies (R) within a groundmass of "bone" coal, the entire fragment embedded in plaster of Paris (Pl).

j Pyrite (P) and kaolinite or calcite (K) associated with vitrain (V), the entire fragment embedded in plaster of Paris (Pl).

k. sp. gr. 2.00 sink (× 25)



l. sp. gr. 2.00 sink (× 25)

FIG. 7D Polished surfaces of fragments of coal and mineral matter from float-and-sink fractions of high specific gravity.

k Fragment composed almost completely of mineral matter—calcite or kaolinite (K), pyrite (P), vitrain (V), embedded in plaster of Paris (Pl).

l Small needlelike fragment of vitrain (V) partly surrounded by kaolinite (K), embedded in plaster of Paris (Pl). A fusain rodlet (F) is also shown.

TABLE 4—*Analyses of the banded ingredients*

1. Moist bands as collected in the mine.
2. Moisture-free.
3. Moisture and ash free.
4. Unit coal B. t. u. (dry, mineral matter-free).

County	Analysis No.	Sample No.	Ingredient	Condition	Moisture	Ash	Volatile matter	Fixed carbon	Sulfur				B. t. u.
									Sulfate	Pyritic	Organic	Total	
Washington (Mine E).	C-375	1	Vitrain	1	12.8	1.5	38.7	47.0	.02	.55	1.39	1.96	12,256
				2		1.7	44.4	53.9	.02	.63	1.60	2.25	14,055
				3			45.1	54.9	.02	.64	1.63	2.29	14,293
				4									14,384
Washington (Mine E).	C-380	2	Vitrain	1	11.8	2.1	39.9	46.2	.00	.51	2.10	2.61	12,204
				2		2.4	45.2	52.4	.00	.58	2.38	2.96	13,837
				3			46.3	53.7	.00	.60	2.43	3.03	14,179
				4									14,292
Washington (Mine E).	C-129	3	Vitrain	1	12.0	1.3	39.7	47.0				2.3	12,281
				2		1.5	45.1	53.4				2.6	13,956
				3			45.8	54.2				2.7	14,165
				4									14,261
Washington (Mine E).	C-130	4	Vitrain	1	9.8	2.3	41.0	46.9				2.8	12,469
				2		2.5	45.5	52.0				3.1	13,824
				3								3.2	14,185
				4									14,300
Washington (Mine E).	C-370	5	Clarain (top coal)	1	9.3	4.5	45.4	40.8	.01	1.37	2.27	3.65	12,316
				2		5.0	50.1	44.9	.01	1.51	2.50	4.02	13,574
				3			52.7	47.3	.01	1.59	2.63	4.23	14,284
				4									14,477

Washington (Mine E).	C-373	6	Clarain (top coal).....	1	10.8	4.9	42.7	41.6	.01	1.40	2.32	3.73	12,006
				2	.....	5.5	47.9	46.6	.01	1.57	2.60	4.18	13,459
				3	.....	.....	50.7	49.3	.01	1.65	2.75	4.42	14,240
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,440
Washington (Mine E).	C-378	7	Clarain (top coal).....	1	9.5	4.1	42.5	43.9	.01	1.24	1.95	3.20	12,356
				2	.....	4.6	46.9	48.5	.01	1.36	2.17	3.54	13,650
				3	.....	.....	49.2	50.8	.01	1.43	2.27	3.71	14,306
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,475
Washington (Mine E).	C-133	8	Clarain (top coal).....	1	6.2	4.9	45.9	43.0	.....	.....	.....	3.7	12,902
				2	.....	5.2	48.9	45.9	.....	.....	1.06	3.9	13,755
				3	.....	.....	51.6	48.4	.....	.....	.....	4.2	14,513
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,702
Washington (Mine E).	C-374	9	Clarain (bottom coal)...	1	10.9	10.8	39.4	38.9	.03	1.88	2.25	4.16	11,018
				2	.....	12.1	44.2	43.7	.03	2.10	2.54	4.67	12,365
				3	.....	.....	50.3	49.7	.03	2.40	2.89	5.32	14,075
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,381
Washington (Mine E).	C-381	10	Clarain (bottom coal)...	1	11.3	11.0	36.9	40.8	.02	.99	1.79	2.80	10,906
				2	.....	12.4	41.5	46.1	.02	1.11	2.02	3.15	12,291
				3	.....	.....	47.4	52.6	.02	1.27	2.31	3.60	14,032
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,295
Washington (Mine E).	C-372	11	Fusain.....	1	11.95	16.42	23.61	48.02	.04	.14	.43	.61	9,339
				2	.....	18.64	26.82	54.54	.04	.16	.50	.70	10,606
				3	.....	.....	32.96	67.04	.05	.20	.61	.86	13,037
				4	.....	.....	.....	.....	.....	.....	.....	.....	13,300
Washington (Mine E).	C-376	12	Fusain.....	1	17.03	14.54	15.38	53.05	.04	.79	.35	1.18	9,431
				2	.....	17.52	18.53	63.95	.05	.96	.41	1.42	11,366
				3	.....	.....	22.46	77.54	.05	1.16	.51	1.72	13,776
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,066
Washington (Mine E).	C-377	13	Fusain.....	1	11.2	21.6	15.2	52.0	.22	6.86	.65	7.73	9,999
				2	.....	24.3	17.1	58.6	.24	7.72	.75	8.71	11,259
				3	.....	.....	22.6	77.4	.32	10.20	.98	11.50	14,866
				4	.....	.....	.....	.....	.....	.....	.....	.....	15,693

TABLE 4—Concluded

County	Analysis No.	Sample No.	Ingredient	Condition	Moisture	Ash	Volatile matter	Fixed carbon	Sulfur				B. t. u.
									Sulfate	Pyritic	Organic	Total	
Jackson (Mine K)....	C-356	14	Vitrain.....	1	10.6	1.2	37.6	50.6	.01	.37	1.14	1.52	12,715
				2	.....	1.4	42.1	56.5	.01	.41	1.28	1.70	14,224
				3	.....	.....	42.6	57.4	.01	.42	1.30	1.73	14,421
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,494
Jackson (Mine K)....	C-354	15	Vitrain.....	1	7.9	2.4	37.9	51.8	.01	.45	1.31	1.77	12,988
				2	.....	2.7	41.1	56.2	.01	.49	1.42	1.92	14,098
				3	.....	.....	42.3	57.7	.01	.50	1.46	1.97	14,481
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,581
Jackson (Mine K)....	C-355	16	Clarain.....	1	7.5	7.7	38.9	45.9	.01	.72	1.54	2.27	12,294
				2	.....	8.4	42.0	49.6	.01	.77	1.68	2.46	13,285
				3	.....	.....	45.8	54.2	.01	.84	1.83	2.68	14,497
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,695
Jackson (Mine K)....	C-350	17	Fusain.....	1	18.01	12.48	18.0	51.51	.05	1.44	.43	1.92	9,939
				2	.....	15.22	21.95	62.83	.06	1.75	.53	2.34	12,122
				3	.....	.....	25.89	74.11	.07	2.07	.62	2.76	14,299
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,590
Franklin (Mine L)....	C-510	18	Vitrain.....	1	8.87	.87	35.60	54.66	.00	.18	.49	.67	13,010
				2	.....	.95	39.07	59.98	.00	.20	.53	.73	14,277
				3	.....	.....	39.44	60.56	.00	.20	.54	.74	14,415
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,447
Franklin (Mine L)....	C-511	19	Vitrain.....	1	7.3	1.7	35.3	55.7	.00	.21	.58	.79	13,048
				2	.....	1.9	38.1	60.0	.00	.23	.62	.85	14,071
				3	.....	.....	38.8	61.2	.00	.23	.63	.86	14,341
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,391

Franklin (Mine L)....	C-509	20	Vitrain.....	1	9.63	.88	33.84	55.65	.00	.13	.56	.69	12,866
				2	.....	.97	37.45	61.58	.00	.15	.61	.76	14,237
				3	.....	.....	37.81	62.19	.00	.15	.62	.77	14,376
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,411
Franklin (Mine L)....	C-503	21	Clarain.....	1	8.6	6.7	35.9	48.8	.00	.21	.48	.69	12,269
				2	.....	7.3	39.2	53.5	.00	.23	.52	.75	13,426
				3	.....	.....	42.3	57.7	.00	.25	.56	.81	14,486
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,600
Franklin (Mine L)....	C-504	22	Clarain.....	1	8.9	5.6	34.5	51.0	.00	.33	.50	.83	12,372
				2	.....	6.1	37.9	56.0	.00	.36	.55	.91	13,582
				3	.....	.....	40.4	59.6	.00	.38	.59	.97	14,471
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,569
Franklin (Mine L)....	C-505	23	Fusain.....	1	8.99	16.91	22.35	51.75	.01	.24	.15	.40	9,335
				2	.....	18.58	24.56	56.86	.01	.26	.17	.44	10,257
				3	.....	.....	30.16	69.84	.01	.32	.21	.54	12,597
				4	.....	.....	.....	.....	.....	.....	.....	.....	12,844
Franklin (Mine L)....	C-506	24	Fusain.....	1	22.80	4.86	6.78	65.56	.01	.21	.13	.35	10,737
				2	.....	6.29	8.78	84.93	.01	.27	.17	.45	13,908
				3	.....	.....	9.37	90.63	.01	.29	.18	.48	14,842
				4	.....	.....	.....	.....	.....	.....	.....	.....	14,937

Analytical Results

The banded ingredient samples were all subjected to proximate analysis, including sulfur and B.t.u. determinations (Table 4). The analyses indicated certain important differences in the character of the ingredients.

The analyses of fusain are typical of the great variability of the moisture and ash content of this material as previously pointed out by Parr and others,[7] due to its porous nature. In mine L, Franklin County (Analyses 23, 24) it may be noted that the moisture content of fusain varies from 8.99 to 22.80 per cent, and the ash content from 4.86 to 16.91 per cent. Air drying loss is high for the same reason. Another noteworthy peculiarity of fusain is a high fixed carbon content, commonly about 75 per cent on a dry ash-free basis. This results in a fuel ratio (F.C./V.M.) commonly between 2.5 and 3.0 (Table 5). The heat value of pure fusain, on a moisture and mineral matter-free basis (unit coal) is commonly about 15,000 B.t.u., although there are erratic variations from this value possibly due to the fact that occasionally fusain will merge gradually into vitrain.

Vitrain is generally characterized by less ash than the other ingredients, and a relatively low moisture and mineral matter-free (unit coal) calorific value.

The composition of clarain does not differ greatly from that of the seam as a whole. The fuel ratio of clarain and vitrain is much less than it is for fusain, but in samples from the same mine the fuel ratio of clarain is found to be lower than that of vitrain. In general there is an increase in the fuel ratio for the bands as well as for the raw coal southeastward across the southern part of the State (Table 5).

Theoretically, unit coal (dry, mineral matter-free) values of standard face samples in a small area such as that represented by the operations of a single mine are essentially uniform, not varying more than 100 units and usually not more than 50 units from a well established value for the mine. Such average values provide a means of determining the probable character of the ingredients as compared with the character of the entire seam. From a general knowledge of the character of clarain it would be expected that the unit coal calorific value of this ingredient would be a little higher than that of the seam as a whole, that vitrain would show a little lower value and that fusain would be above the average. These probabilities are based on supposition supported by observation that vitrain contains less hydrogen than clarain, and that the carbon content of fusain is usually very high.

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[7] Parr, S. W., Hopkins, H. C., and Mitchell, D. R., Fusain: Industrial and Engineering Chemistry, Vol. 3, p. 64, Jan. 15, 1931.

TABLE 5.—*Fuel ratios of banded ingredients*

(Fixed carbon/volatile matter)

County	Vitrain	Clarain	Fusain
Washington	1.2	1.11	2.0
	1.15	1.03	2.0
	1.18	1.03	3.4
	1.14	1.06	.....
	.....	1.01	.....
	.....	1.11	.....
Average	1.16	1.06	2.46
Jackson	1.34	1.18	2.86
	1.37	.....	.....
Average	1.35	1.18	2.86
Franklin	1.54	1.36	2.3
	1.57	1.48	9.6
	1.64	.....	.....
Average	1.58	1.42	5.95

Analyses of face samples and of samples of the banded ingredients from mine E, Washington County, mine K, Jackson County, and mine L, Franklin County, are available for comparison. The data (Table 6) indicate that for these three mines, at least, the unit coal B.t.u. value of vitrain averages less than, and that of clarain about the same as, the average B.t.u. value for the seam in each case. The values for fusain are exceedingly irregular, so that averages mean very little, but it is apparent that values may be very high.

The point to be made is that there is some possibility of variation in heat value of the prepared coal due to the concentration of one or the other of the ingredients in one or more of the fractions.

TABLE 6.—*Unit coal calorific values of face samples and samples of banded ingredients*

County	Kind	Analysis number	Unit B. t. u.				
			Individual values	Composite	(No.)	Average	(No.)
Washington	Face	C-367,368,369	14502,14348,14367	14393	(3)	*14406*	(3)
	Vitrain	C-375,380,129,130	14383,14292,14261,14300			14309	(4)
	Clarain (top coal)	C-370,373,378,133	14477,14440,14475,14702			(*a*) 14464	(3)
						14464	(3)
	Bottom coal	C-374,381	14381,14295			14381	(2)
	Fusain	C-372,373	13300,14066,15693			14353	(3)
Jackson	Face	A-90723, –4	14645,14737			*14691*	(2)
	(Composite)	A-90760		14642	(2)		
	Vitrain	C-356,354	14494,14581			14538	(2)
	Clarain	C-355	14695			14695	(1)
	Fusain	C-350	14590			14590	(1)
Franklin	Face	C-492,495	14550,14505				
	(Composite)	C-507		14528	(2)		
	Face	C-493,494	14551,14533			*14535*	(4)
	(Composite)	C-508		14622	(2)		
	Vitrain	C-510,511,509	14447,14391,14411			14416	(3)
	Clarain	C-503,504	14600,14569			14586	(2)
	Fusain	C-505,506	12844,14937			13,890	(2)

(*a*) Average of first three only, omitting 14,702.

DISCUSSION OF TEST RESULTS

Washability Curves

Washability curves based on ash and sulfur determinations of float-and-sink fractions are in general use, and their construction is understood, so that it is not necessary to present an explanation here. Bulletin 217 of the Engineering Experiment Station, University of Illinois, contains complete information on the methods of calculation, construction, and interpretation of this type of curve. (Figs. 8, 9, 10, and 11.)

Heat Value Curves

A main purpose of the investigation was the determination of the distribution of heat values in the fractions produced by the float-and-sink procedure. Supplementary heat value curves, when added to the diagrams showing standard washability curves, provide desirable data upon which to base cleaning procedure. Probably B.t.u. determinations cannot be generally employed in such tests because of their cost, nor are they always necessary, but some information of this sort is desirable for a better understanding of all the effects of gravity separation upon Illinois coals. In certain cases the possibility of raising the standard of a coal to meet specifications, thereby improving its sales mobility, may give to the variations in heating value greater significance than usually attaches to it in cleaning practice. (Figs. 8, 9, 10, and 11.)

For the purposes of this study dry B.t.u. determinations of the float-and-sink fractions of the coal were generally obtained in addition to the usual ash determinations. The small amount of coal in the fractions above 1.70 specific gravity made such calorific determinations impracticable for such samples. The 100 per cent heat value for curve B is the heat value of the face sample where this was available. If this value was not available, it was determined graphically.[8]

The calculations necessary for the construction of the heat distribution curves involve the same procedure as the calculation of the ordinary float-and-sink curves. The Coal Recovery-B.t.u. curve is constructed by plotting the cumulative weight per cent of the coal as ordinate and the cumulative B.t.u. as abscissa. The curve shows the B.t.u. value of the coal at any percentage recovery, and conversely, if it is desired to produce a coal of a certain B.t.u. standard, this curve indicates the percentage of total feed recovered.

[8] See Figure 1, p. 48, A preliminary report on unit coal-specific gravity curves for Illinois coals (this report).

The determined B.t.u. of each fraction is assumed to be the heat value of the mid-point of the gravity range of the fraction. Therefore, in plotting the B.t.u. distribution curve, the mid-point of the weight per cent of each fraction (this equals ½ the weight plus the sum of the weights preceding in each case) is used as ordinate and the correspond-

TABLE 7.—*Comparison of the coals at 5 per cent recovery intervals*

Sample	Coal recovery	Ash	B. t. u. value (dry)	B. t. u. recovered	B. t. u. increase
	Per cent	*Per cent*		*Per cent*	*Per cent*
A	100	13.62	11,756	100	.....
	95	10.6	12,300	98.6	.....
	90	9.0	12,580	96.0	7.0
	85	8.0	12,720	92.0	.....
B	100	13.45	11,796	100	.....
	95	10.8	12,200	98.9	.....
	90	9.1	12,500	96.0	6.0
	85	8.0	12,650	91.0	.....
C	100	13.37	11,791	100	.....
	95	10.0	12,350	99.5	.....
	90	8.0	12,850	97.5	9.0
D	100	12.24	11,533	100	.....
	95	9.5	11,750	99.8	.....
	90	7.8	12,350	97.0	7.1
E	100	13.82	11,743	100	.....
	95	11.5	12,150	98.5	.....
	90	9.8	12,420	95.1	5.8
	85	8.5	12,600	91.5	.....
	80	7.6	12,780	87.2	.....
F	100	14.28	11,615	100	.....
	95	10.3	12,400	98.2	.....
	90	8.5	12,680	97.5	9.1
	85	7.5	12,820	93.4	.....
G	100	15.05	11,698	100	.....
	95	11.2	12,320	99.5	.....
	90	9.5	12,680	97.2	8.4
	85	8.1	12,850	93.0	.....
H	100	9.85	12,743	100	.....
	95	7.2	13,200	98.5	.....
	90	6.5	13,300	94.0	4.4
I	100	10.26	12,778	100	.....
	95	7.5	13,150	98.0	.....
	90	6.5	13,325	94.0	4.3
J	100	9.29	12,933	100	.....
	95	7.0	13,300	98.0	.....
	90	6.2	13,475	94.0	4.2

ing determined B.t.u. as abseissa. This curve shows the heat characteristies of the coal sample from the lightest to the heaviest fraetions, and reveals the extremely low heat value of the heavy fractions.

The Coal Reeovery-B.t.u. Recovery curve is constructed by using the eoal weight per eent of the fraetions as ordinate and the eorresponding cumulative B.t.u. per eent as abseissa. This curve when used with the Coal Recovery-Ash and the Coal Recovery-Sulfur curves reveals the conditions most favorable for separation from the standpoint of quality and maximum recovery.

As a further demonstration of the value of B.t.u. distribution data when used with the conventional float-and-sink information, a table has been prepared (Table 7) showing the effect upon B.t.u. reeovery of each 5 per eent deerease in eoal recovery until 6 to 8 per eent ash is reached. A tonnage rejeetion of 10 per cent (90 per eent recovery) entails a heat loss of 2½ to 6 per cent, representing the fuel discarded. But there is an improvement in the quality of the eoal of from 542 to 1,065 B.t.u. per pound (4.2 to 9.1 per cent), the improvement for eoals from areas outside Franklin and Williamson eounties being somewhat greater than that for the coal from within these eounties. Natural low-ash eoal such as from mines H, I and J, lose more heat value as tonnage recovery is lowered by refuse rejection than do high-ash coals beeause of the relatively larger amount of coal lost.

Regional Variation

The ten coals to which this investigation applied represent the two most important varieties of eoal mined in Illinois from the standpoint of produetion, namely the coal from southwestern Illinois mined in the Belleville and Standard districts and the coal from the southern Illinois Franklin-Williamson district. The Herrin (No. 6) coal in the southern Illinois field is slightly higher in rank and lower in ash and sulfur than the eoal from this same bed in southwestern Illinois. The unit coal calorifie value of the coal in southwestern Illinois varies from about 14,350 to 14,450; that in southern Illinois from 14,500 to 14,700.

Mines A to G inclusive represent coals in southwestern Illinois; mines H, I, and J represent southern Illinois eoals. Certain similarities are found in the curves of each group of eoals so that in discussing briefly the characteristics of the eurves it is eonvenient to group them geographieally.

A summary of the float-and-sink data appears in Table 8.

TABLE 8.—*Tabulation of float-and-sink data*

Per cent by weight, per cent ash, sulfur, and B. t. u. values of fractions at different specific gravities

(Moisture Free)

Sample No.	Less than 1.30 Sp. Gr.				1.30-1.35 Sp. Gr.				1.35-1.40 Sp. Gr.				1.40-1.50 Sp. Gr.			
	Weight	Ash	Sulfur	B. t. u.	Weight	Ash	Sulfur	B. t. u.	Weight	Ash	Sulfur	B. t. u.	Weight	Ash	Sulfur	B. t. u.
A	42.9	4.7	3.1	13,325	24.1	8.6	3.4	12,539	11.8	13.7	3.9	11,740	8.2	19.5	3.7	10,861
B	48.7	5.3	3.4	13,236	21.5	10.1	4.0	12,251	9.2	12.6	4.2	11,863	7.4	18.9	4.9	10,817
C	63.5	5.4	3.2	13,224	10.8	9.8	3.4	12,457	6.9	13.3	3.4	11,878	6.5	17.6	3.5	11,110
D	48.7	4.9	3.4	12,985	19.8	7.6	2.9	12,358	11.5	11.5	4.0	11,695	8.6	17.7	4.2	10,676
E	63.4	5.7	3.5	13,108	8.2	12.9	3.7	11,813	8.5	17.4	3.5	11,163	6.3	23.5	3.7	10,193
F	45.6	4.9	3.2	13,317	25.0	8.1	3.2	12,579	10.0	13.8	3.3	11,698	7.1	19.5	3.4	10,748
G	51.7	4.9	1.1	13,368	21.2	9.7	1.2	12,629	6.2	15.5	1.0	11,748	4.9	21.2	1.1	10,843
H	64.7	3.8	1.3	13,666	16.0	9.8	1.2	12,783	6.8	15.3	1.3	11,953	5.0	21.3	1.4	10,983
I	56.8	4.0	1.0	13,676	26.5	8.0	1.0	13,030	5.5	16.4	1.1	11,741	4.4	23.3	1.1	10,704
J	67.9	4.3	1.2	13,752	16.9	10.7	1.4	12,739	5.5	16.0	1.9	11,802	4.3	21.7	2.0	10,903

Sample No.	1.50-1.70 Sp. Gr.				1.70-2.0 Sp. Gr.				Greater than 2.0 Sp. Gr.			
	Weight	Ash	Sulfur	B. t. u.	Weight	Ash	Sulfur	B. t. u. (*a*)	Weight	Ash	Sulfur	B. t. u. (*a*)
A	5.2	31.4	4.3	8,919	2.3	47.0	5.7	.....	5.5	65.6	20.8	.....
B	4.9	30.6	5.5	8,885	2.7	45.6	6.8	6,400	5.6	60.9	23.3	3,865
C	3.4	29.9	3.7	9,084	1.9	44.7	6.2	.....	7.0	70.8	13.0	.....
D	5.0	31.1	4.8	8,674	2.2	48.1	6.4	.....	4.2	68.8	16.5	.....
E	6.8	32.7	3.6	8,534	2.2	47.5	5.6	.....	4.6	63.5	21.7	.....
F	3.3	30.0	4.6	8,896	1.3	46.4	5.0	6,000	7.7	73.6	12.8	1,205
G	3.5	32.1	1.2	8,936	5.3	38.2	1.4	7,868	7.2	73.8	1.9	1,670
H	3.2	33.2	1.5	9,127	1.7	40.3	2.4	8,025	2.6	75.6	6.8	2,515
I	2.3	33.0	1.1	9,020	1.3	47.5	1.9	.....	3.2	77.2	4.4	.....
J	2.2	33.9	2.7	8,895	1.5	47.9	3.8	.....	1.7	73.4	8.0	.....

(*a*) Values determined graphically.

Southwestern Illinois Group

COAL RECOVERY–ASH CURVE

The A curves for these coals show a change in slope toward the lower end at 85 to 90 per cent recovery. Cleaning of such coals to provide a low ash content (about 8 per cent) commonly necessitates a loss of weight of about 10 to 15 per cent. (Figs. 8, 9, and 10.)

ASH DISTRIBUTION CURVES

The curves of Ash Distribution for the group are fairly regular, in general not having the sharp change in direction indicative of an easy separation of coal and mineral matter. These curves, therefore, like the Coal Recovery-Ash curves, indicate a disseminated distribution of the mineral matter in the coal. The D curve for mine B is exceptional in this group as it indicates a rather sudden increase in mineral matter at the 80 per cent recovery point.

REFUSE REJECT–ASH CURVES

The Refuse Reject–Ash curves in this group of coals are like the curves last described only moderately concave upward for the same reason.

SULFUR CURVES

In general the sulfur curves of these coals indicate high pyritic sulfur content and break sharply in the portion representing the heavy fractions. Cleaning, even at high gravities with minimum loss in weight of the coal, would materially reduce the sulfur content, particularly when the sulfur content exceeds 5 per cent.

B.T.U. DISTRIBUTION CURVES

The B.t.u. distribution curves are based on values either determined in the laboratory or by extrapolation and represent the calorific characteristics of any portion of the coal from the lightest to the heaviest fractions. The C curve in the southwestern Illinois group flattens markedly at about 90 per cent recovery thus indicating that the increment beyond this point has little calorific value. This is in contrast to the curves of the southern group which cross the 90 per cent recovery line with a somewhat higher B.t.u. value and maintain their steepness beyond 90 per cent recovery.

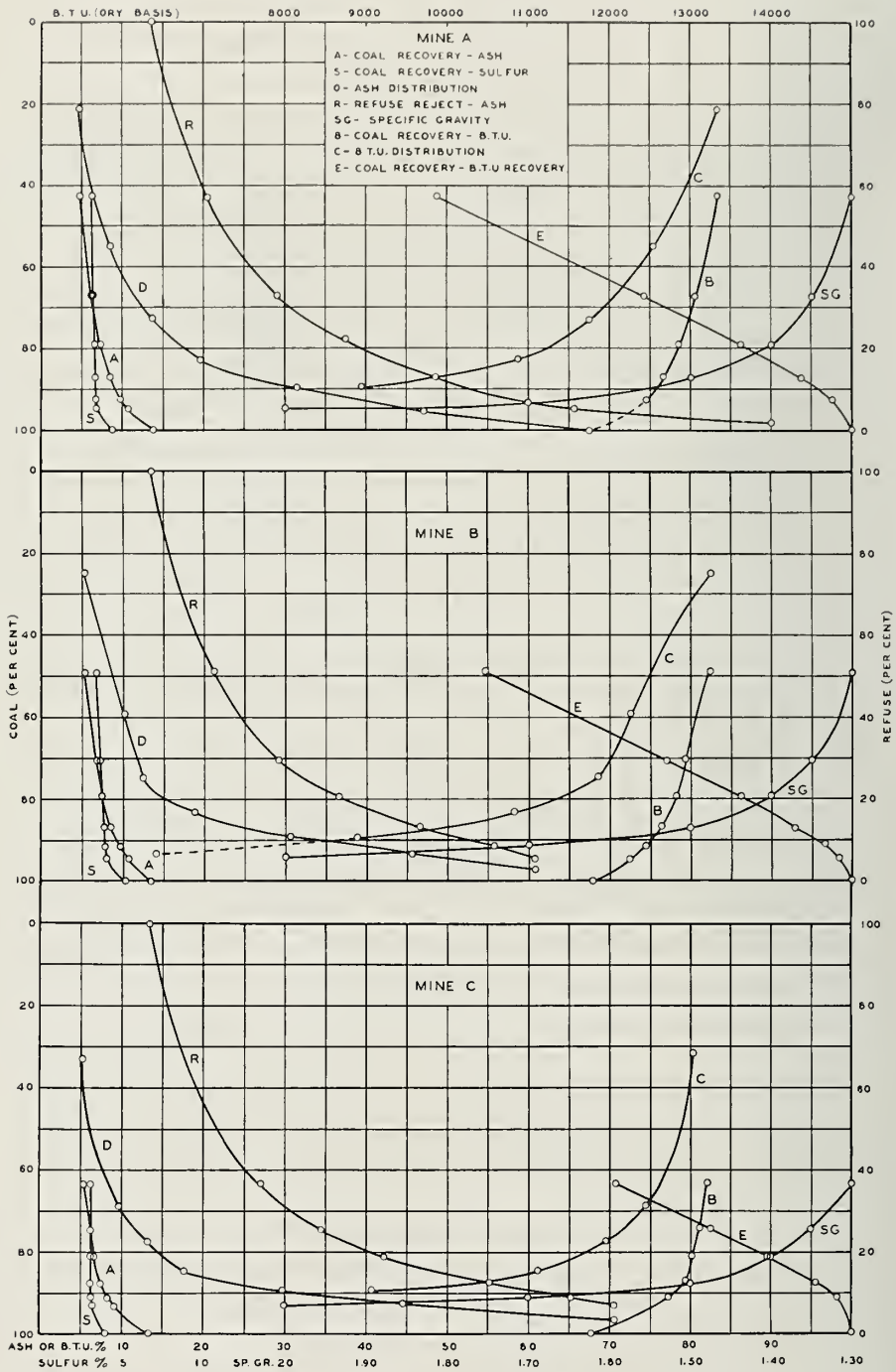

FIG. 8. Washability curves of Mines A, B, and C.

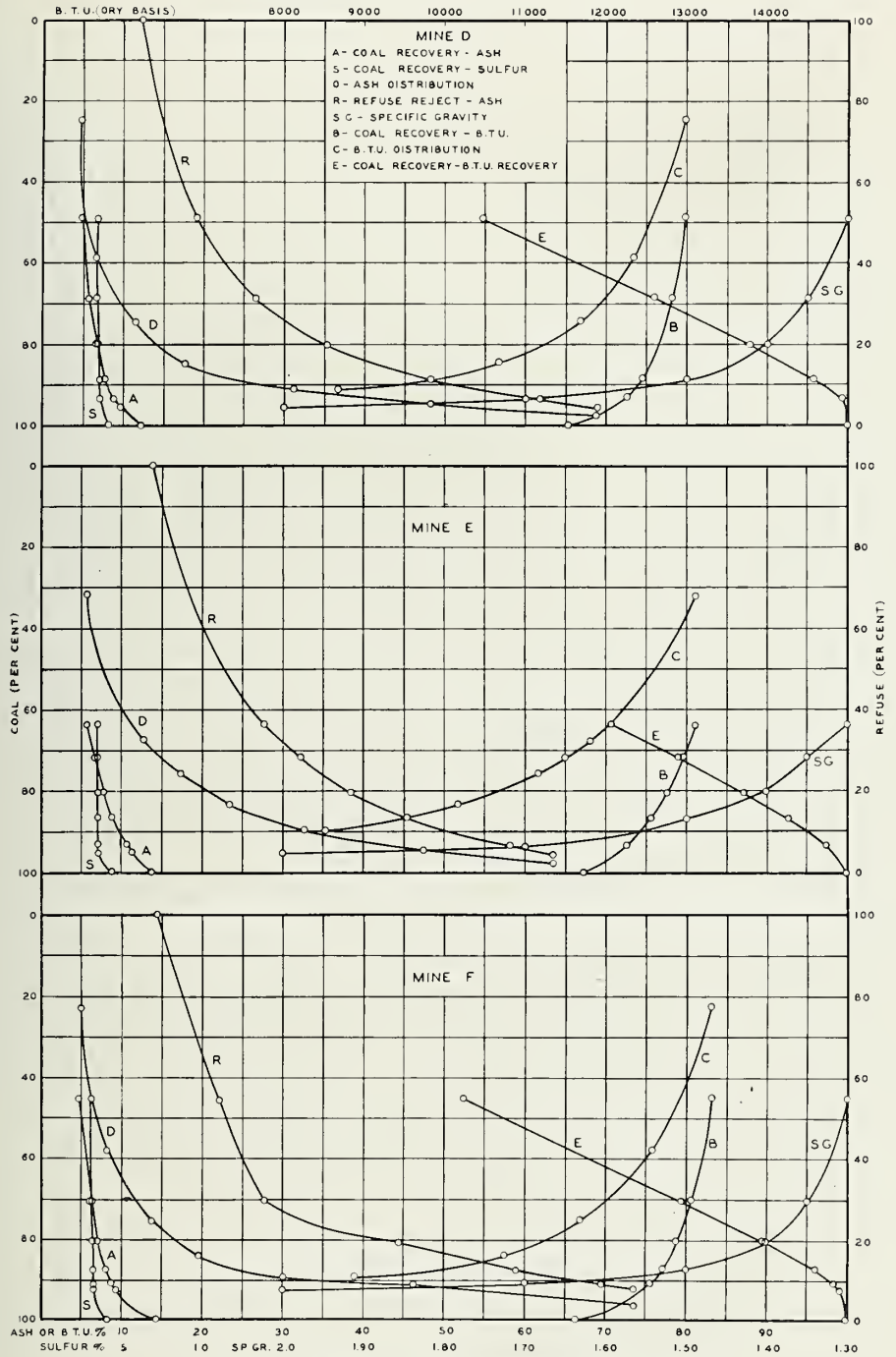

Fig. 9. Washability curves of Mines D, E, and F.

COAL RECOVERY–B.T.U. RECOVERY CURVES

The Coal Recovery-B.t.u. Recovery curve is a straight line with a sharp break at the end; this break for the group under consideration generally takes place at about the 90 per cent recovery point indicating that there is relatively little heat loss in the first 10 per cent of reject. This supports the interpretation of curve B and the general conclusion that the main benefit in cleaning these coals will be derived by rejection of not more than 10 per cent. It is thus shown that 10 per cent tonnage rejection does not entail a like loss of the available B.t.u.; curve E indicates that 95 to 98 per cent of the B.t.u. is retained at ninety per cent tonnage recovery for the coals tested.

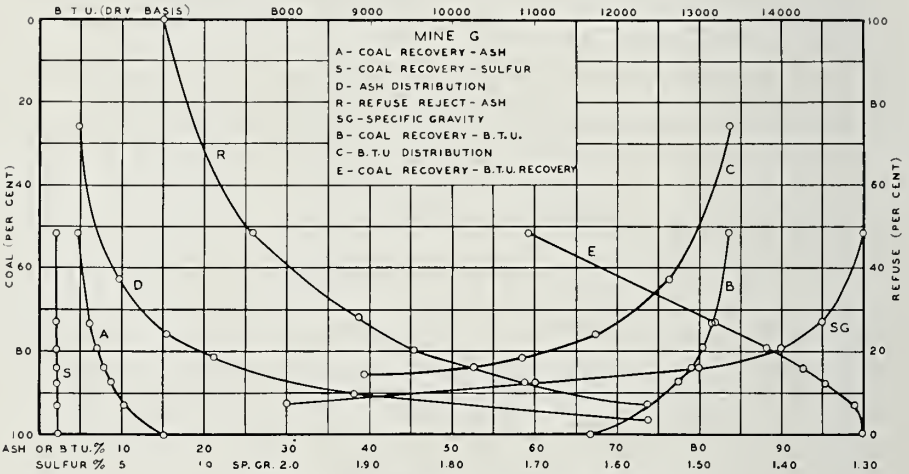

Fig. 10. Washability curves of Mine G.

Southern Illinois Group

WASHABILITY CURVES

The curves A, D, and R contrast with similar curves for the coals from southwestern Illinois in having sharper breaks, indicating less disseminated ash. The amount of mineral matter can be reduced but little without considerable coal losses. It is probable that rejections greater than 5 per cent are not practicable for the coals tested. (Fig. 11.)

As indicated by the S curves, the sulfur is evenly disseminated through the coal and no material reduction can be expected by washing.

CALORIFIC VALUE CURVES

The calorific value curves (B, C, and E), show that a rejection of 5 per cent refuse has little effect on the B.t.u. values but rejections greater than this amount entail considerable heat loss.

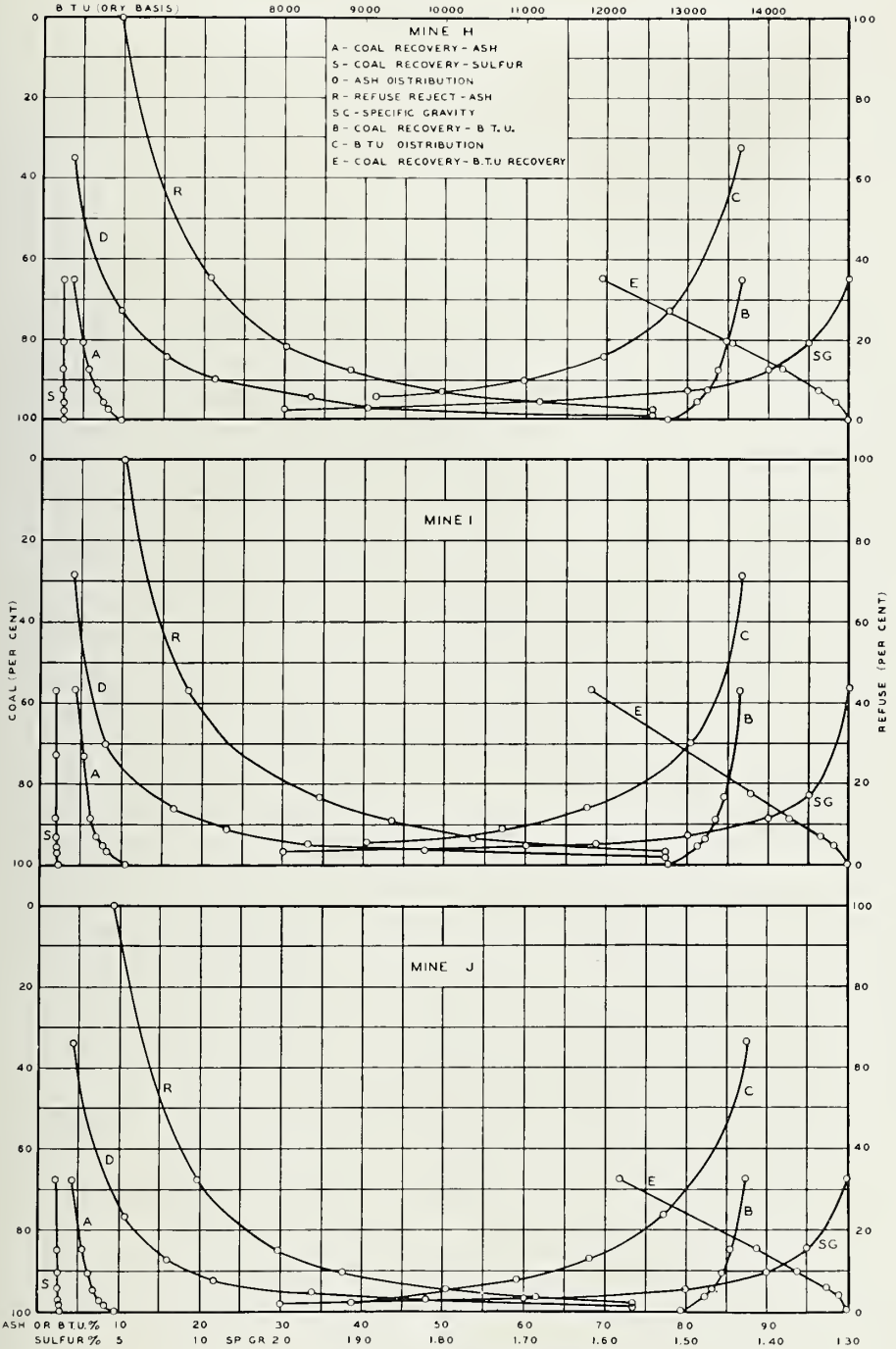

FIG. 11. Washability curves of Mines H, I, and J.

Specific Gravity

The specific gravity curve shows the specific gravity at which a separation must be made in order to obtain a product of the desired ash content or heating value.

SUMMARY AND CONCLUSIONS

Herrin (No. 6) coal of the Illinois coal basin is a normal banded bituminous coal containing the usual banded ingredients, vitrain, clarain, fusain, and durain, usually only the first three but in places all four, and mineral impurities. When the coal is crushed to small sizes (minus ¼ inch in these experiments) the banded ingredients and the impurities are separated and appear in more or less discrete particles. However, the foremost problem in the improvement of the coals is that of removing the mineral impurities, the effect of which is measured not merely by the loss in tonnage or the improvement in ash content, but also by the effect on the heat value of the coal.

The coals of southwestern Illinois investigated in this series of tests have an average ash content of 13.7 per cent and can be cleaned to an 8 per cent ash content by rejecting 10 to 15 per cent of the tonnage as refuse. The coals from southern Illinois (Franklin-Williamson district) that were tested can be cleaned to a 7 per cent ash content by rejecting 5 per cent of the tonnage or to 6.4 per cent by rejecting 10 per cent.

In general 25 per cent of the total sulfur can be eliminated in the southwestern Illinois coals tested when cleaning is carried out at 85 to 90 per cent recovery, whereas in the southern group only slight sulfur reduction can be expected from mechanical cleaning.

It is generally recognized that an important advantage of cleaned over uncleaned coal is its higher B.t.u. value. The variations in B.t.u. value in coal subjected to the cleaning process are therefore of interest and have received particular emphasis in these studies. The series of curves that have been constructed showing the nature of variations in the heat value of different fractions of the coal provide a means, in addition to the usual washability curves, for determining the most desirable point for separating coal from ash and sulfur and in standardizing the B.t.u. of the coal as it is marketed.

It was found that in cleaning the coals of the southwestern Illinois group to about 8 per cent ash the average tonnage recovery was 87 per cent. The B.t.u. recovery, however, was 94.2 per cent and the heat value of the clean coal was increased to 12,671 B.t.u. (dry) as compared with 11,704 for the uncleaned coal. In addition to the improvement in the

fuel due to the ash and sulfur removal, the cleaned coal contains 8.3 per cent more heat than the coal that has not been cleaned.

Cleaning the coals in the southern Illinois group to obtain a 90 per cent recovery provides a coal with 6.4 per cent ash, and 94 per cent of the B.t.u. is recovered. The average dry B.t.u. of the cleaned coal is 13,366 as compared with 12,818 in the uncleaned coal, an improvement of 3.5 per cent.

These results of float-and-sink tests on representative samples of No. 6 coal from various mines in southwestern and southern Illinois indicate in only a general way the possibilities for improvement of these coals by mechanical means. The data presented for any particular mine are in themselves insufficient basis for establishing cleaning procedure. Extensive sampling and testing of the sizes to be mechanically cleaned should precede any decision in regard to the type or capacity of a cleaning plant which will best meet the needs of a particular mine.

The attention given in this report to the banded ingredients in coal No. 6 is in line with the emphasis placed on the fundamental constitution of Illinois coal in investigations that have been carried on by the State Geological Survey during the last four years. There is an increasing realization of the heterogeneous constitution of our coals, and that they are composed of several distinct materials rather than of a single substance. The float-and-sink tests for determining the washability of coals provide additional evidence, beyond that furnished by concurrent microscopic studies, of the lack of uniformity in the character of the material and of the tendency of different ingredients to accumulate in the different fractions in proportions quite different from those in which they occur in the coal as a whole. That this would probably be the case is more or less obvious, if once the heterogeneity of the coal material is realized. It is one purpose of the present report to encourage this realization.

With respect to the banded ingredients of the coal, the present tests and others that preceded have shown that fusain, and to a less extent vitrain, breaks into small particles in the mining and preparation processes and tends to become concentrated in the "carbon" sizes. Fusain is largely removed in the minus 48 mesh material, which was not subjected to the float-and-sink procedure in the present series of tests. It was found that concentrations of vitrain of 71.3 per cent can be obtained in the coal floating at 1.30 specific gravity, whereas the fractions 1.35 to 1.70 contain 91.7 per cent of the clarain.

In American practice, there is little practical application made of the effect of variations in amounts of coal ingredients on the use of coal. Such applications are confined almost entirely to the regulation of fusain in coal used for coking purposes. Such regulation may consist of (1)

limitation of fusain by removal of sizes in which it tends to concentrate (dedusting) or (2) careful mixing practices to avoid segregation of this constituent. It is now fairly common practice in both wet and dry cleaning processes to dedust and so remove the fusain which is concentrated in the fine sizes.[8] It is noteworthy that in a few cases European preparation is considerably more advanced commercially, permitting the rearranging of the component parts in combinations other than in those in which they occur in the seam.

It is with the belief that, with increasing scientific information in regard to the nature of the coal and its components, such preparation may promise a profitable procedure in the near future, and with the hope of stimulating further researches in the possible separation of these ingredients and their effect on the utilization of coal, individually or in certain definite proportions, that the results of these cleaning tests have been included in this report.

[8] Hebley, Henry F., The Dedusting of Coal, Transactions A.I.M.M.E., Vol. 108, Coal Division, 1934, p. 88-127.

A PRELIMINARY REPORT ON UNIT COAL-SPECIFIC GRAVITY CURVES OF ILLINOIS COALS

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A PRELIMINARY REPORT ON UNIT COAL-SPECIFIC GRAVITY CURVES OF ILLINOIS COALS*

By L. C. McCabe,[1] D. R. Mitchell,[2] and G. H. Cady[3]

INTRODUCTION

For purposes of classification, the relative constancy of the pure coal substance is assumed.

This assumption has been carried to the extent of constructing a dilution curve[4] based on the determined B.t.u. and ash content of the coal. It is generally concluded, from empirical data, that this dilution curve is essentially a straight-line curve.

The dilution curves for the coals under consideration are shown in figure 1. The dry ash and B.t.u. values of the series of float-and-sink fractions were used in establishing the points which determine the direction of the curve.

Space does not permit the consideration of each curve in detail but some characteristics which are common to almost all the curves may be pointed out. By referring to Table 1 and figure 1 it may be seen that the intermediate fractions of 1.35, 1.40, and 1.50 specific gravity, which constitute the greater weight per cent of a given coal sample, fall more frequently on a straight dilution line than do the lighter or heavier fractions of the same sample. In most instances there is a marked steepening of the curve between the 1.35 and the fraction of lightest gravity (1.30). In general the curve also increases in steepness between the fractions of 1.50 and 1.70 specific gravity. Gründer[5] pointed out the deviation of high-ash fractions from a straight line, and Thiessen and

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[1] Assistant Geologist, Coal Division, Illinois State Geological Survey.
[2] Assistant Professor, Mining and Metallurgical Engineering, University of Illinois, Urbana.
[3] Senior Geologist and Head of Coal Division, Illinois State Geological Survey.

[4] Brinsmaid, W., The amount of inert volatile matter in mineral constituents of coal: Jour. Ind. and Eng. Chem., Vol. I, p. 65, 1909.
Stansfield, E., and Sutherland, J. W., Determination of mineral matter in coal and fractionation studies of coal: Trans. A.I.M.E. Coal Div. pp. 614-626, 1930.

[5] Gründer, W., Waschkurven and heizwert, Glückauf, Vol. 68, pp. 114-119, Jan. 30, 1932.

Reed[6] have recently indicated an apparent uncertainty of points representing low-ash fractions of Illinois coals.

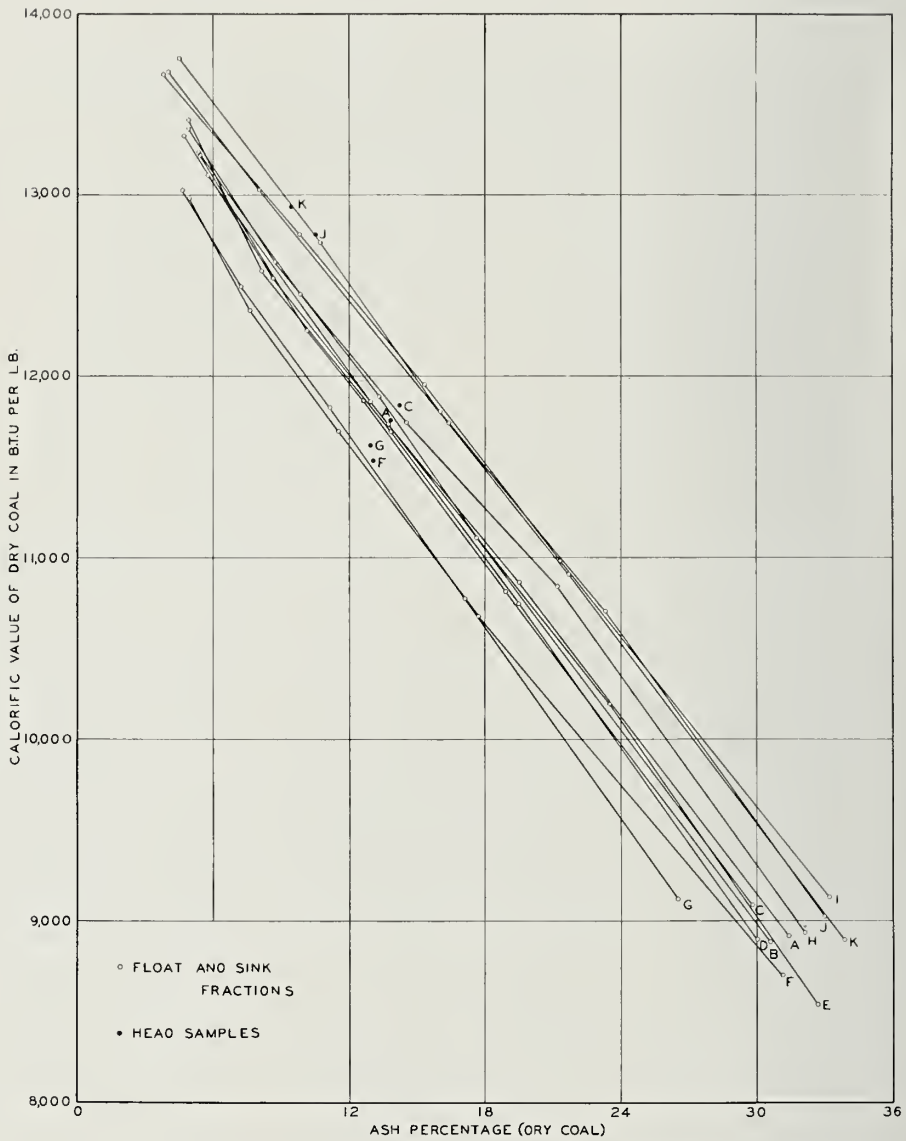

Fig. 1. Dry coal, calorific value-ash curves.

It will be noted in figure 1 that the head samples invariably occupy a position above the dilution curve determined by the corresponding

[6] Thiessen, G., and Reed, F. H., Studies of the graphical method for calculating pure coal calorific values. Fuel Vol. 13, pp. 168-175, 208-217, 1934; Illinois State Geological Survey Report of Investigation No. 32, 1934.

FIG. 2. Map showing locations of mines sampled and areas of districts VI and VII of the Illinois Mining Investigations.

float-and-sink fractions. Cawley[7] and Gooskov[8] have gone beyond the scope of this paper in determining the cause of the apparent deterioration of coals floated in organic solutions.

UNIT COAL-SPECIFIC GRAVITY CURVES

The dilution curves (Fig. 1) provide a variety of ash- (or mineral matter) free values depending upon what portion of the curve is projected as a straight line to the O-ash boundary. For this reason consideration of the unit coal values (Parr formula)[9] of the fractions obtained by float-and-sink method was desirable.

Mine Sampling and Laboratory Procedure

The mines A to L inclusive (Fig. 2) all operate in the Herrin (No. 6) coal in southwestern (A-G) or southern (I-L) Illinois that is, in districts VI and VII of the Illinois Mining Investigations.[10]

A standard channel sample from roof to floor was taken for the float-and-sink tests. Nothing was excluded in taking the sample except in the case of mine E in Washington County where the clay "blue band" of No. 6 coal has an abnormal thickness of 8 inches and was not included in the sample. All samples tested in this study were ground to minus 1/4 inch. In the first series of samples, eighteen to twenty months expired between the date of sampling and the date of analysis. In the second series of samples (three samples from mine E) analysis was within two weeks of the time of sampling.

Float-and-sink separations were made using mixtures of benzene, carbon tetrachloride, and bromoform following the procedure used by Callen and Mitchell.[11] In the first series of samples, fractions floating in liquids of specific gravities 1.30, 1.35, 1.40, 1.50, 1.70, 2.0, and the fraction sinking in the 2.0 solution furnished the material for analysis. In the second series of samples from mine E in Washington County,

[7] Cawley, R. L., Notes on the determination of the calorific values of high-ash coal: Fuel, Vol. 11, No. 8, pp. 302-303, 1932.
Cawley, R. L., Notes on use of different media for float-and-sink tests on coal: Fuel, Vol. 11, p. 303, 1932.

[8] Gooskov, W., An experiment on parallel float-and-sink testing in carbon-tetrachloride and zinc chloride: Colliery Guardian, Sept. 16, 1932, pp. 517-518.

[9] Parr, S. W., and Wheeler, W. F., Unit coal and the composition of coal ash: Univ. of Illinois Eng. Exp. Sta. Bull. 37, 1909.

[10] Preliminary report on organization and method of investigation: Illinois State Geol. Survey Cooperative Mining Investigations Bull. 1, p. 12, 1912.

[11] Callen, Alfred C., and Mitchell, David R., Washability Tests of Illinois Coals: Univ. of Illinois Eng. Exp. Station Bull. 217, p. 32, 1930.

float fractions were removed from solutions of 1.275, 1.30, 1.35, 1.40, 1.50, and 1.70 specific gravity. The fraction sinking in the solution of 1.70 specific gravity was the end of the series.

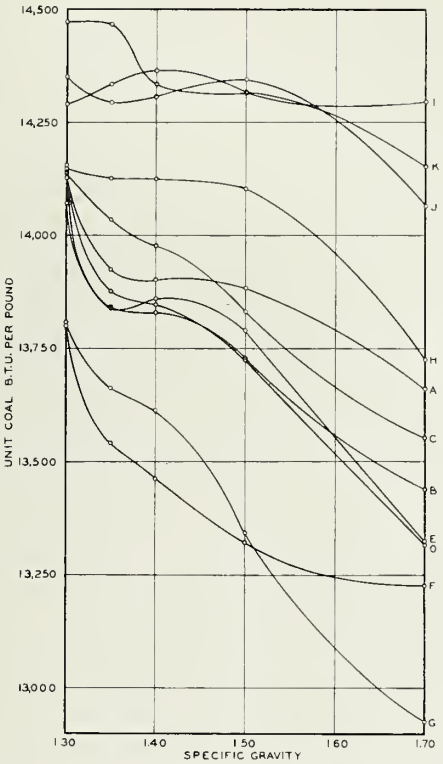

Fig. 3. District unit coal-specific gravity curves, by mines.
District VII (Belleville), Mines A–E.
District VII (Central), Mines F–G.
District VI (Southern), Mines I–K.
District VI–VII boundary, Mine H.

Plotting of Data

A curve was plotted for each sample with unit coal values as ordinates and specific gravities as abscissas (Fig. 3). Data representing values obtained from different samples from the same mine produce similar curves. The chart shows two small groups of characteristic curves, each group representing samples from adjacent mines, suggesting the possibility that a distinct type of curve may characterize the coal in each district.

District Curves

DISTRICT VII

District VII embraces a part or all of fifteen counties (Fig. 2) in the southwestern part of the coal basin.

The curves for this district (Fig. 3) fall into two separate groups; A, B, C, D, and E from mines in St. Clair, Washington, and Randolph

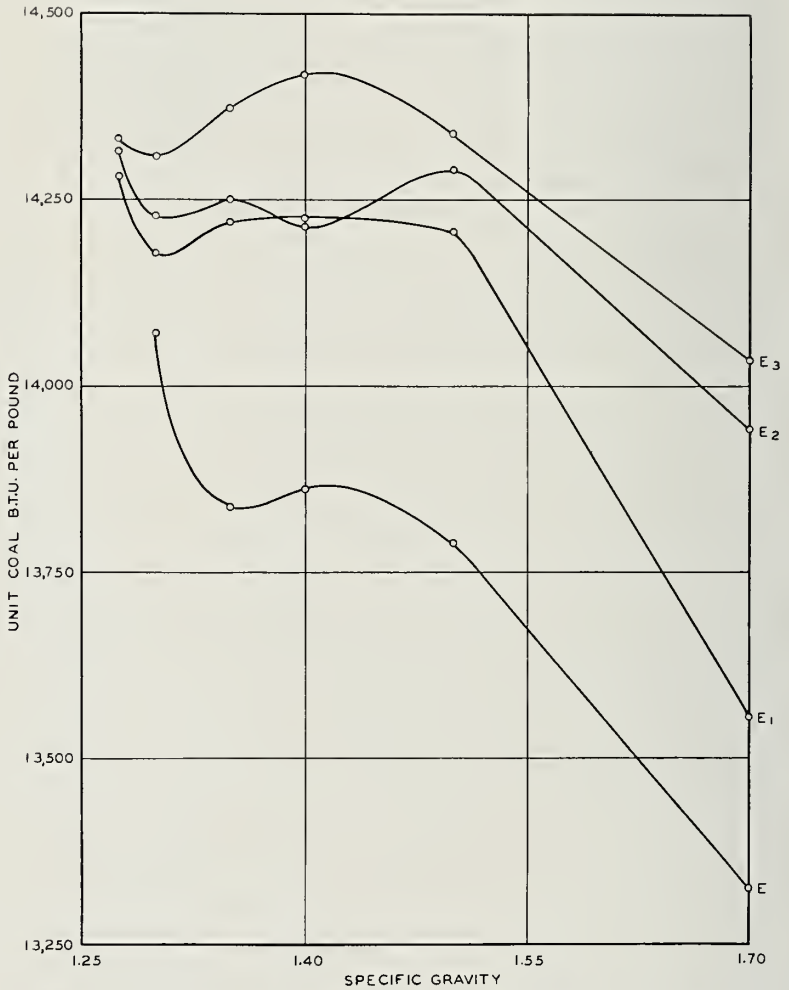

Fig. 4. Graph showing comparative values for fresh (E_1, E_2, E_3) and stored (E) coals.

counties taking similar form and comparable positions while F and G, from mines in Macoupin and Montgomery counties respectively, assume a lower and different form on the graph.

The A-E curves are distinguished by a flattening or reversal in direction caused by a low unit B.t.u. in the fraction of 1.35 specific

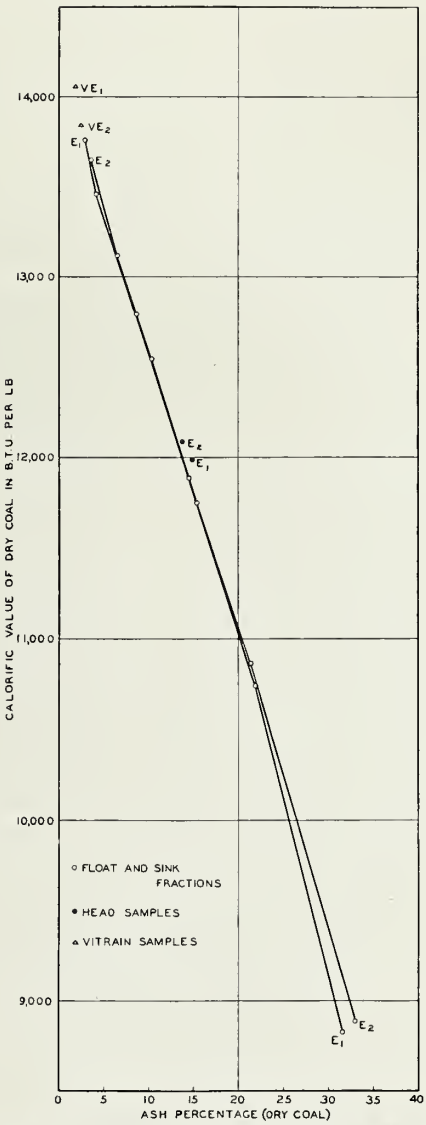

FIG. 5. Graph showing relation of values for vitrain (VE_1, VE_2) and head samples (E_1, E_2) from the same mine to dry coal calorific value-ash curves.

gravity relative to the 1.40 fraction. This is only barely perceptible in the G-curve which is geographically farthest removed from the A-E

group. The F-curve which is derived from a sample intermediate between the G-sample and the A-E group flattens considerably in the fractions of 1.35 and 1.40 specific gravity.

As noted above, resampling of mine E in Washington County was undertaken to verify results as there had been a considerable lapse of time between sampling the mines and analysis of float-and-sink fractions and head samples. The results of this check are shown graphically in figure 4. Curve E of figure 3 is reproduced in figure 4 to facilitate comparison with the curves of the check samples E_1, E_2, and E_3. In

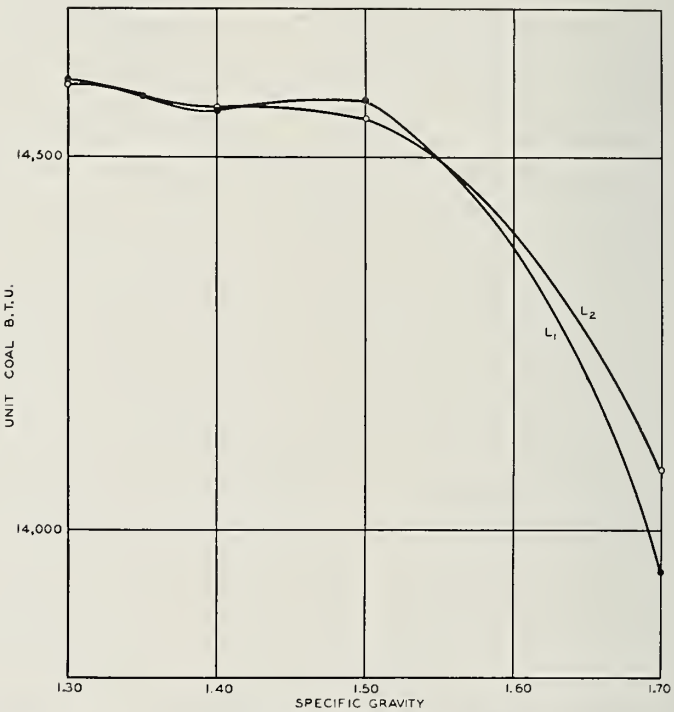

FIG. 6. Unit coal-specific gravity curves based on duplicate portions of the same sample.

general form and relative position of fractions, the four are similar with the exeeption of the low position of the 1.40 specific gravity fraction of curve E_2. The markedly lower position of curve E in relation to the other three is undoubtedly due to oxidation in storage.

DISTRICT VI

District VI, with mines for the most part operating in No. 6 (Herrin) coal, produees a greater tonnage than any other district in the state. The mines sampled are all in the No. 6 seam.

Curves I and J are based on data obtained from samples in mines that are only a little more than a mile apart whereas the mine represented by sample K is about 7 miles to the south. Although there is no marked parallelism in form in this group, the differences are small and the group is confined to a narrow range and to a distinct position with relation to the other curves.

Curve H, which represents a sample from near the boundary of districts VI and VII, occupies an intermediate position between the two groups.

The curves L_1 and L_2 (Fig. 6) are constructed from data obtained from a single sample collected in mine L (Fig. 2), in the northwest part of district VI. The sample was riffled into two equal parts which were carried through the float-and-sink and analytical procedure as two separate samples to test the possibility of duplicating results on identical materials.

SIGNIFICANCE OF DATA

Although the purpose of this paper is to present the data obtained, there are certain implications which might be of value in further study of this problem.

The variations in the curves of figures 3 and 4, as well as those observed in the dilution curves (Fig. 1), may be due to one or more factors. Those which appear to be pertinent to this problem are (1) variation in coal substance with change in specific gravity, (2) variation in kind and quantity of mineral matter with the specific gravity of the fraction, (3) factors of analytical procedure which tend to introduce error in analysis, particularly in high-ash and high-sulfur fractions.

Variations in the Coal Substance

Advances in microscopic investigations of coal have revealed that a considerable range of materials enters into the constitution of almost all coals. These studies indicate that not a single "pure coal" but numerous "pure coals" comprise a seam.

It is shown in Table 3 (p. 16) that the separation of Illinois coals into several well chosen gravity fractions by float-and-sink methods tends to concentrate vitrain in the light, clarain in the intermediate, and pyrite and other mineral matter, and to some extent fusain, in the heavy fractions.

Vitrain concentration in the fractions of 1.275 and 1.30 specific gravity appear to be responsible for the initial steepness of the curves of figures 1, 3, and 4. This is substantiated by plotting the pertinent data

of available vitrain samples on figure 5. When the two channel samples E_1 and E_2 were taken, vitrain samples corresponding in locality were secured. These hand-picked vitrain samples are identified with the dilution curves of figure 5; e. g., the channel sample furnishing the curve E_1 and the vitrain sample whose position on the figures is numbered VE_1 are from the same locality in the mine. The position of the vitrain is above the curve of the fractions from the same room. This is possibly due to the fact that the vitrain was separated by hand and was not subjected to the apparent deteriorating effect of organic solutions. A more complete treatment of the chemical significance of the constituents appears in another place.

The Rôle of Mineral Matter in Curve Variation

No detailed information on the nature of the mineral matter as distinguished from ash is available for the fractions separated. In the heaviest fractions (2.0 sink) pyrite, calcite, kaolinite, and undifferentiated shale particles are present.

Further investigations which might have some bearing on this phase of the problem are (1) the possibility of regional or district mineral suites, (2) the variation in the nature of mineral matter from fraction to fraction within the same sample, and (3) the relationship of mineral derived CO_2 to the B.t.u. values of the fractions which determine the curves.

Factors of Analytical Procedure in Curve Variation

Considerable difficulty is encountered in determining the B.t.u. values of high-ash and high-sulfur fractions. The difficulties in calorimetry undoubtedly contribute to the marked decline in B.t.u. in the 1.70 specific gravity fraction and consequently are in part responsible for the terminal steepness of the curves of figures 1, 2 and 3.

TABLE 1.—*Analyses of float-and-sink fractions*

Sample	Condition	Analysis dry basis			Moisture and ash free		Unit coal
		Ash	Sulfur	B. t. u.	Sulfur	B. t. u.	B. t. u.
		Per cent	*Per cent*		*Per cent*		
Mine A	Float 1.30	4.7	3.1	13,325	3.3	13,984	14,128
	Float 1.30–1.35	8.6	3.4	12,539	3.8	13,725	13,923
	Float 1.35–1.40	13.7	3.9	11,740	4.5	13,609	13,900
	Float 1.40–1.50	19.5	3.7	10,861	4.6	13,495	13,882
	Float 1.50–1.70	31.4	4.3	8,919	6.2	13,008	13,660
	Float 1.70–2.00	47.0	5.7	.....	10.8	.....	.....
	Sink 2.00	65.6	20.8	.....	60.7	.....	.....
	Untreated (head sample)	13.8	4.4	11,756	5.1	13,634	13,953
Mine B	Float 1.30	5.3	3.4	13,236	3.6	13,980	14,139
	Float 1.30–1.35	10.1	4.0	12,251	4.5	13,634	13,869
	Float 1.35–1.40	12.6	4.2	11,863	4.8	13,578	13,859
	Float 1.40–1.50	18.9	4.9	10,817	6.1	13,332	13,750
	Float 1.50–1.70	30.6	5.5	8,885	7.9	12,795	13,468
	Float 1.70–2.00	45.6	6.8	.....	12.5	.....	.....
	Sink 2.00	60.9	23.3	.....	59.5	.....	.....
Mine C	Float 1.30	5.4	3.2	13,224	3.4	13,981	14,137
	Float 1.30–1.35	9.8	3.4	12,457	3.8	13,806	14,034
	Float 1.35–1.40	13.3	3.4	11,878	3.9	13,694	13,976
	Float 1.40–1.50	17.6	3.5	11,110	4.3	13,482	13,830
	Float 1.50–1.70	29.9	3.7	9,084	5.3	12,967	13,551
	Float 1.70–2.00	44.7	6.2	.....	11.3	.....	.....
	Sink 2.00	70.8	13.0	.....	44.7	.....	.....
	Untreated (head sample)	14.2	4.3	11,791	5.02	13,745	14,066

TABLE 1—Continued

Sample	Condition	Analysis dry basis			Moisture and ash free		Unit coal
		Ash	Sulfur	B. t. u.	Sulfur	B. t. u.	B. t. u.
		Per cent	*Per cent*		*Per cent*		
Mine D	Float 1.30	4.9	3.2	13,317	3.4	14,003	14,155
	Float 1.30–1.35	8.1	3.2	12,579	3.4	13,691	13,878
	Float 1.35–1.40	13.8	3.3	11,698	3.9	13,570	13,848
	Float 1.40–1.50	19.5	3.4	10,748	4.3	13,359	13,725
	Float 1.50–1.70	30.0	4.6	8,896	6.5	12,703	13,318
	Float 1.70–2.00	46.4	5.0	.....	9.3	.....	.....
	Sink 2.00	73.6	12.8	.....	48.6	.....	.....
	Untreated (head sample)	14.2	3.94	11,871	4.59	13,840	14,159
Mine E (Sample E)	Float 1.30	5.7	3.5	13,108	3.7	13,902	14,070
	Float 1.30–1.35	12.9	3.7	11,813	4.3	13,557	13,837
	Float 1.35–1.40	17.4	3.5	11,163	4.3	13,522	13,859
	Float 1.40–1.50	23.5	3.7	10,193	4.9	13,320	13,789
	Float 1.50–1.70	32.7	3.6	8,534	5.3	12,682	13,323
	Float 1.70–2.00	47.5	5.6	.....	10.7	.....	.....
	Sink 2.00	63.5	21.7	.....	59.4	.....	.....
	Untreated (head sample)	13.5	4.81	11,743	5.56	13,573	13,897
Mine E (Sample E_1)	Float 1.275	2.8	3.02	13,762	3.11	14,153	14,281
	Float 1.275–1.30	4.1	3.18	13,460	3.32	14,035	14,177
	Float 1.30–1.35	8.6	3.62	12,796	3.96	14,001	14,219
	Float 1.35–1.40	14.5	3.92	11,882	4.59	13,896	14,220
	Float 1.40–1.50	21.9	4.08	10,732	5.23	13,743	14,208
	Float 1.50–1.70	31.6	4.20	8,825	6.14	12,907	13,554
	Sink 1.70	56.6	16.36	.....	37.66	.....	.....
	Untreated (head sample)	14.8	4.50	11,940	5.28	14,021	14,367

Mine E (Sample E_2)	Float 1.275	3.6	3.75	13,651	3.89	14,158	14,315
	Float 1.275–1.30	6.5	3.99	13,117	4.27	14,028	14,228
	Float 1.30–1.35	10.3	4.19	12,544	4.68	13,985	14,248
	Float 1.35–1.40	15.3	4.10	11,749	4.85	13,873	14,213
	Float 1.40–1.50	21.4	4.18	10,865	5.32	13,825	14,286
	Float 1.50–1.70	33.0	4.36	8,855	6.50	13,208	13,940
	Sink 1.70	58.6	18.74		45.26		
	Untreated (head sample)	13.7	4.71	12,089	5.46	14,010	14,349
Mine E (Sample E_3)	Float 1.275	3.9	4.03	13,611	4.20	14,162	14,331
	Float 1.275–1.30	6.3	4.31	13,210	4.60	14,096	14,306
	Float 1.30–1.35	10.1	4.61	12,670	5.13	14,099	14,371
	Float 1.35–1.40	15.8	4.41	11,828	5.23	14,042	14,417
	Float 1.40–1.50	21.6	4.36	10,866	5.55	13,854	14,337
	Float 1.50–1.70	33.3	5.08	8,849	7.62	13,274	14,035
	Sink 1.70	53.2	18.00		38.46		
	Untreated (head sample)	14.6	5.10	12,064	5.98	14,135	14,502
Mine E (Sample VE_1)	Hand picked vitrain	1.7	2.25	14,055	2.29	14,293	14,384
Mine E (Sample VE_2)	Hand picked vitrain	2.4	2.96	13,837	3.03	14,179	14,292
Mine F	Float 1.30	4.9	3.4	12,985	3.6	13,658	13,800
	Float 1.30–1.35	7.6	2.9	12,358	3.1	13,377	13,540
	Float 1.35–1.40	11.5	4.0	11,695	4.5	13,213	13,463
	Float 1.40–1.50	17.7	4.2	10,676	5.1	12,977	13,321
	Float 1.50–1.70	31.1	4.8	8,674	7.0	12,596	13,226
	Float 1.70–2.00	48.1	6.4		12.4		
	Sink 2.00	68.8	16.5		52.8		
	Untreated (head sample)	13.0	4.7	11,533	5.3	13,256	13,552
Mine G	Float 1.30	4.6	3.7	13,025	3.8	13,652	13,807
	Float 1.30–1.35	7.2	4.0	12,498	4.3	13,468	13,661
	Float 1.35–1.40	11.5	3.8	11,828	4.2	13,360	13,613
	Float 1.40–1.50	17.1	4.4	10,774	5.3	12,996	13,341
	Float 1.50–1.70	26.5	5.2	9,116	7.1	12,408	12,925
	Float 1.70–2.00	39.5	8.6		14.3		
	Sink 2.00	70.8	15.8		54.0		
	Untreated (head sample)	12.9	5.22	11,622	5.99	13,338	13,655

TABLE 1—Concluded

Sample	Condition	Analysis dry basis			Moisture and ash free		Unit coal
		Ash	Sulfur	B. t. u.	Sulfur	B. t. u.	B. t. u.
		Per cent	*Per cent*		*Per cent*		
Mine H	Float 1.30	4.9	1.1	13,368	1.1	14,062	14,148
	Float 1.30–1.35	9.7	1.2	12,629	1.3	13,993	14,145
	Float 1.25–1.40	15.5	1.0	11,748	1.2	13,896	14,143
	Float 1.40–1.50	21.2	1.1	10,843	1.4	13,767	14,102
	Float 1.50–1.70	32.1	1.2	8,936	1.8	13,166	13,725
	Float 1.70–2.00	38.2	1.4	.....	2.3	.....	.....
	Sink 2.00	73.8	1.9	.....	7.3	.....	.....
	Untreated (head sample)	14.8	1.1	11,925	1.29	14,001	14,231
Mine I	Float 1.30	3.8	1.3	13,666	1.3	14,201	14,290
	Float 1.30–1.35	9.8	1.2	12,783	1.4	14,164	14,334
	Float 1.35–1.40	15.3	1.3	11,953	1.6	14,114	14,364
	Float 1.40–1.50	21.3	1.4	10,983	1.8	13,954	14,316
	Float 1.50–1.70	33.2	1.5	9,127	2.3	13,655	14,296
	Float 1.70–2.00	40.3	2.4	.....	3.9	.....	.....
	Sink 2.00	.....	.....	.....	.....	.....	.....
Mine J	Float 1.30	4.0	1.0	13,676	1.1	14,268	14,351
	Float 1.30–1.35	8.0	1.0	13,030	1.1	14,165	14,294
	Float 1.35–1.40	16.4	1.1	11,741	1.4	14,048	14,307
	Float 1.40–1.50	23.3	1.1	10,704	1.5	13,952	14,346
	Float 1.50–1.70	33.0	1.1	9,020	1.7	13,453	14,063
	Float 1.70–2.00	47.5	1.9	.....	3.7	.....	.....
	Sink 2.00	77.2	4.4	.....	19.4	.....	.....
	Untreated (head sample)	10.5	1.13	12,778	1.26	14,271	14,450

Mine K	Float 1.30	3.7	1.3	13,752	1.4	14,373	14,472
	Float 1.30–1.35	10.7	1.9	12,739	2.1	14,271	14,467
	Float 1.35–1.40	16.0	1.9	11,802	2.2	14,059	14,334
	Float 1.40–1.50	21.7	2.0	10,903	2.5	13,923	14,315
	Float 1.50–1.70	33.9	2.7	8,895	4.0	13,467	14,151
	Float 1.70–2.00	47.9	3.8	.....	7.3	.....	.....
	Sink 2.00	73.4	8.0	.....	30.0	.....	.....
	Untreated (head sample)	9.4	1.6	12,933	1.7	14,276	14,446
Mine L (Sample L_1)	Float 1.30	4.3	.93	13,897	.97	14,528	14,604
	Float 1.30–1.35	11.8	1.04	12,692	1.18	14,397	14,582
	Float 1.35–1.40	15.9	.78	12,037	.92	14,307	14,561
	Float 1.40–1.50	20.6	.71	11,312	.90	14,249	14,577
	Float 1.50–1.70	32.6	.59	9,019	.98	13,385	13,944
	Float 1.70–2.00	41.2	.87	.....	1.49	.....	.....
	Sink 2.00	77.9	3.78	.....	17.14	.....	.....
Mine L (Sample L_2)	Float 1.30	4.4	.92	13,876	.96	14,521	14,598
	Float 1.30–1.35	12.4	.97	12,598	1.10	14,385	14,581
	Float 1.35–1.40	15.3	.87	12,134	1.02	14,327	14,567
	Float 1.40–1.50	20.3	.76	11,338	.96	14,224	14,551
	Float 1.50–1.70	33.9	.61	8,910	.93	13,489	14,083
	Float 1.70–2.00	45.6	1.74	.....	3.20	.....	.....
	Sink 2.00	78.9	3.83	.....	18.16	.....	.....

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